THE INFLUENCE OF CLIMATE
ON THE
DEVELOPMENT OF AGRICULTURAL
WATER SUPPLIES IN CANTERBURY

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ABSTRACT

This study evaluates the influence of climate in the development of agricultural water supplies in Canterbury. A discussion of the historical and spatial occurrence is presented, as well as a description of the suitability of the region to such development.

The influence of climate is assessed by the provision of a measure of agricultural drought. This measure is achieved by the utilisation of the concept of potential evapotranspiration in the calculation of the soil water deficits. Description of the spatial variation of the annual soil deficit is provided. The annual soil water deficit is used in statistical analysis against various expressions of interest in irrigation development, and also against actual development in terms of the area border-dyked each season.

It is concluded that there is indeed a tendency for climate, particularly drought, to influence the development of agricultural water supplies. It is, however, difficult to indicate its precise influence due to the involvement of other factors.

CHAPTER ONE

INTRODUCTION

PURPOSE OF STUDY

Longterm records show that droughts may occur in any part of New Zealand, but they are most frequent and severe east of the main divide in the South Island, especially in Canterbury and North Otago (Bondy, 1950). Periods with little or no rainfall are a commonplace feature of the Canterbury weather pattern (Bondy, 1950; Crowder, 1975). Records of droughts in New Zealand extend back to 1855, indeed droughts have been recorded for as long as meteorological observations have been made. A number of analyses of climatic periodicity have been made; including Bondy (1950) and Johnston (1958). None of the published analyses deal specifically with drought periodicity, except those by Bondy (1950), Rickard (1960), Rickard and Fitzgerald (1969). However, these analyses do not discuss drought incidence region by region.

As well as a long history of drought occurrence in Canterbury, there is also a long history of interest in artificial water supplies for agriculture, either stock water races or irrigation. The development of artificial water supplies in Canterbury has been accompanied by numerous publications, especially under the auspices of the Winchmore Irrigation Research Station.

Hitherto, these two seemingly parallel themes which occur in the literature - the incidence of drought and the development of water supplies for stock and irrigation purposes - have remained largely unconnected. As the provision of a water supply is one of the responses available to the dryland farmer in combating the drought hazard (Figure 1.1), the occurrence of drought and its relationship to the innovation of artificial water supplies is worthy of consideration.

The first aim of this study is to establish the occurrence of agricultural drought in Canterbury as far back as climatological records will allow, and to provide a measure of relative severity. The second aim is to study the factors involved in the development of water supplies on the Canterbury Plains, and to determine the influence of climate on this development, in relation to the other factors.

The study is confined to two forms of artificial water supply; stock water races, particularly before 1930, and, large-scale government sponsored irrigation schemes developed since 1930. No data is presented on the development of small-scale private irrigation schemes.

THE DROUGHT PHENOMENON IN NEW ZEALAND

Drought is only one of the variety of natural hazards to which New Zealand is subject. Table 1.1, which is based upon government departmental figures for drought relief, provides an indication of only a small proportion of the total cost of a drought, for much of the cost to the nation is 'hidden'. Maunder (1971) has suggested that a more realistic estimate of cost may be 8 to 15 times greater than that based on claims (Table 1.2).

The dryland farmer has a range of strategies open to him to combat the detrimental effects of drought. The strategies adopted may range from those traditional, to the uncommon (Parkhill, 1971).

Unlike the natural hazard of flooding, drought cannot be prevented by adopted practices, but only reduced in terms of its effects. The practices which may be adopted are seen as a hierarchy of alternatives (Figure 1.1).

TABLE 1.1: THE COSTS OF HAZARDS BASED ON RECORDED CLAIMS 1967-70

Flood	$ 7,800,000
Earthquake	$ 3,680,000
Drought Subsidies	$ 3,700,000
Disease Control	$ 7,450,000
Noxious Weeds	$ 3,000,000

(Source - Appendices to the House)

TABLE 1.2: SUMMARY OF ESTIMATED "COSTS" OF THE 1969/70 DROUGHT IN NEW ZEALAND

Item	Reason	High Cost (1) ($000,000)	Low Cost (2) ($000,000)
Livestock	Stock Movements	0.50	0.25
Wheat	Lower Production	5.00	3.00
Fertilizer	Subsidies	6.75	2.70
Drought Relief	Budget Provision	3.80	2.85
Rural Lending	Budget Provision	6.00	2.00
Electric Power	Thermal Plants - Fuel	3.50	2.80
Forest Fire Losses	Additional Losses	0.15	0.12
Forest Fire Prevention	Additional Costs	0.14	0.07
Dairy Production	Lower Production	15.00	6.80
Lamb Production	Lower Production	1.50	1.00
Wool Production	Lower Production	4.48	2.70
	TOTAL	46.82	24.29

(1) Probable maximum cost

(2) Probable minimum cost

(Source: Maunder, 1971)

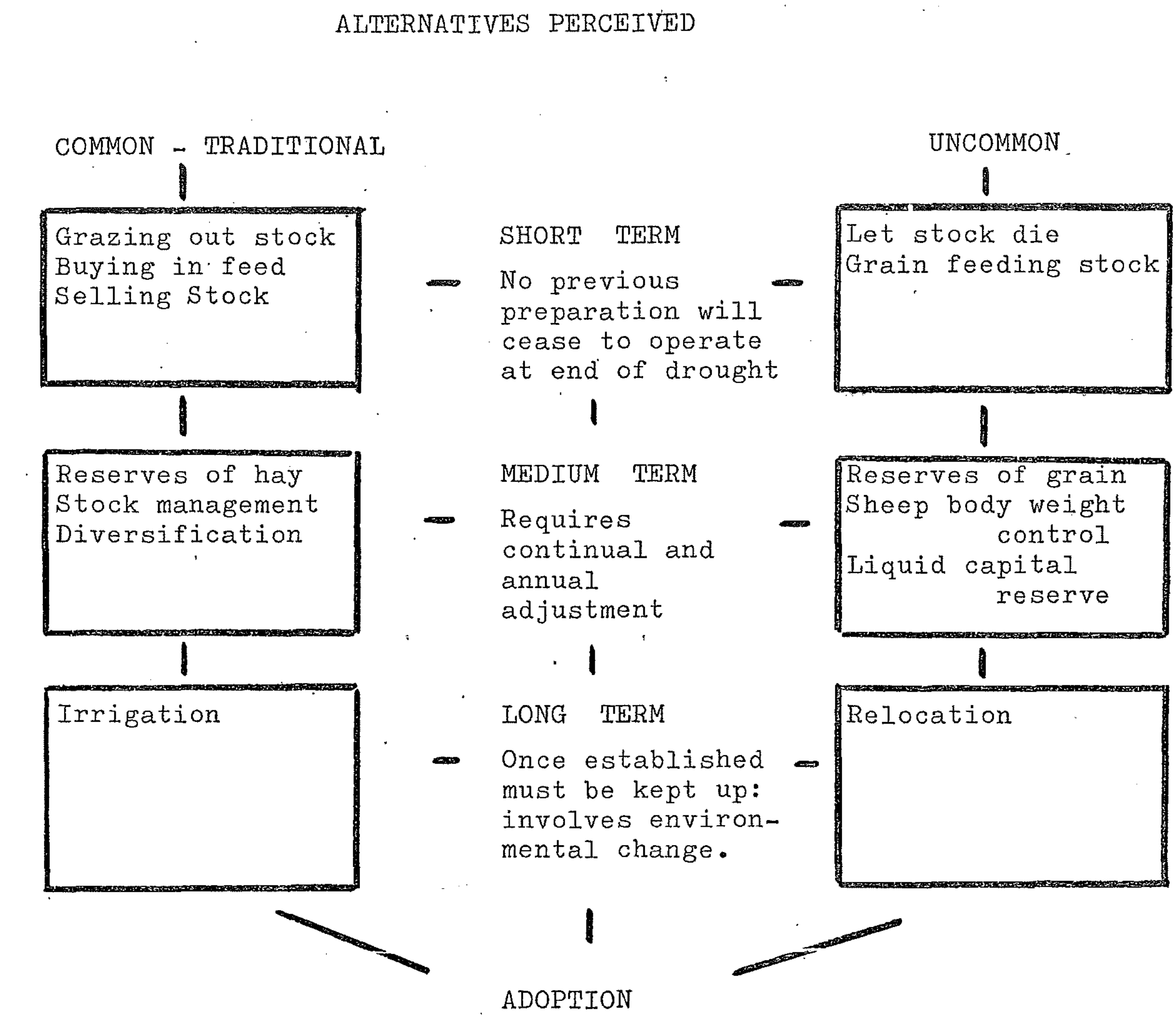


Figure 1.1: THE PERCEPTION - ADOPTION HIERARCHY OF THE DRYLAND FARMER

Source: Parkhill (1971)

They vary from short term alternatives; or those needing no prior preparation, to the long term which not only require previous preparation, but heavy investments of both time and finance on the part of the farmer or government.

National government involvement in irrigation dates only from the 1930s, thus Parkhill's (1971) study shows that most of the strategies that have been adopted to combat the effects of drought in Canterbury have been of short or medium term duration. In conjunction, the trend in Canterbury away from the simple and arable pastoral system of the 1920s, which was less susceptible to drought, to a greater emphasis on cropping means the irrigation need is probably more critical than formerly.

A DEFINITION OF DROUGHT

It is generally accepted that a drought constitutes a 'severe water shortage', but there is no universally agreed definition of the hazard due to the variation in water requirements of the various plant, animal and human communities. There are three major obstacles to arriving at a generally accepted definition of drought. First, it is impossible to divorce the concept of drought from the use to which water is put. Second, due to the uncertainty and variation in the spatiotemporal nature of the hazard it is often easier to define drought after the event than during the period when it is gradually and imperceptibly altering in intensity (Saarinen, 1966). The final factor which negates any set definition of drought is 'the changing pace of man's knowledge and technology' (Burton and Kates, 1964).

Palmer (1965) lists seven definitions of drought which have been divided by Heathcote (1967) into four main categories.

1. Definitions which specify a certain critical minimum amount of rainfall over a certain time period. Among the best known are the British definitions of "absolute drought" and "partial drought". These have a certain convenience for statistical purposes, but they are unsatisfactory in other respects, such as the failure to distinguish between the effects of the same low amount of rainfall in summer, with high evaporation, and in winter, with low evaporation.
2. Definitions which refer to a deficiency of rainfall in broader terms, such as being below a specified percentage of the normal over several months.
3. Definitions which refer explicitly or implicitly to a "moisture deficiency" in the soil. For example, Van Bavel and Verlinden, quoted by Rickard (1960), define agricultural drought as a "condition in which there is insufficient soil moisture available to the crop". A definition referring rather more to relative conditions is that of Palmer (1965), "drought is.... a prolonged and abnormal moisture deficiency".
4. Finally, there are definitions which refer to the effects of drought on crops, animals and various human activities. Thus, Heathcote (1967) states, ".... I shall define drought as occurring whenever it is said to occur". This suggested definition may obviously lead to difficulties, as for example, when the farmers in a certain area say that there is a drought but a more impartial authority disagrees.

Kidson (1931) and Bondy (1950), when describing past droughts in New Zealand, base their definitions on rainfall measurements. Rickard (1960) argues that such definitions bear little relationship to droughts experienced in agriculture, where the main concern is the growing plant and its water supply.

In Canterbury a period without rain in midwinter would hardly constitute a drought, however, a similar period in mid-summer could reduce the moisture in the soil to below wilting point. This concept of drought induced Rickard (1960) to rephrase definitions by Van Bavel and Verlinden (1956) to derive the following definition of agricultural drought:

> "Agricultural drought exists when the soil moisture in the root zone, is at or below permanent wilting point. The condition continues until rain falls in excess of the daily evapotranspiration".
>
> (Rickard, 1960)

MEASUREMENT AND ASSESSMENT OF DROUGHT SEVERITY

Each definition of drought is likely to be associated with a particular method of assessing drought severity. It is unfortunate that, as the definition becomes more satisfactory, the assessment tends to become more complex and difficult.

From Rickard's (1960) definition it is apparent that a more accurate indication - from an agricultural point of view - of the comparative "dryness of periods" is provided by measurement of the average level of soil moisture deficit. The factors which determine the amount of soil moisture are rainfall and the evapotranspiration.

Rickard and Fitzgerald's (1970) lament on the paucity of New Zealand evapotranspiration data remains valid today. Relevant field studies have been concerned with the two separate aspects of evapotranspiration: evaporation (e.g. Finkelstein, 1973) and transpiration (e.g. Rowley and Rowley, 1976). This has meant evapotranspiration studies in New Zealand have relied on estimates of evapotranspiration. In this study rainfall records are used along with one particular estimate of evapotranspiration. The estimate derived by Thornthwaite (1948) has been used at several New Zealand locations (Rickard, 1957;

Rickard and Fitzgerald, 1960), and it has the advantage of simplicity. For these reasons the Thornthwaite estimate was selected for this study.

THE THORNTHWAITE ESTIMATE

Thornthwaite (1948) defined evapotranspiration as,

> "the combined evapotranspiration from the soil surface and transpiration from plants..... the transport of water from the earth back to the atmosphere, the reverse of precipitation."

In the same paper, he used the now well known concept of 'potential evapotranspiration', as the maximum evapotranspiration which could occur under a particular set of climatic conditions, and gave details of how this could be estimated from readily available meteorological records: the mean screen temperature, and the length of day. The resulting calculated moisture loss from the soil can be combined with the known moisture gain (measured rainfall) to obtain an estimate of the changes in soil moisture. In 1955, a modification was made which enabled actual evapotranspiration to be calculated from potential evapotranspiration by taking into account the effect of increasing soil moisture tension (Thornthwaite and Mather, 1955). This was extended in 1957 to the presentation of tables giving the soil moisture retained after different amounts of potential evapotranspiration have occurred, for soils with storage capacities from 25 cm to 400 cm (Thornthwaite and Mather, 1957).

Although the concept of potential evapotranspiration was introduced by Thornthwaite as an aid in the delineation of climatic zones, it has found considerable application in a wide variety of agroclimatological problems, and this has been its main value in New Zealand. One of the more important applications of evapotranspiration studies is their possible use in estimating irrigation requirements, and in providing a basis for the scheduling of applications of irrigation water. Rickard's (1956) work at Winchmore established that it was possible to use the Thornthwaite estimation of potential evapotranspiration (P.E.) to calculate the soil moisture deficit under pasture just prior to irrigation.

The application of the P.E. calculation was extended as an aid to the irrigating farmer in Canterbury in two ways (Rickard and Fitzgerald, 1970). Forms could be obtained from Winchmore Irrigation Research Station which included mean daily P.E. values for each month from September-April, spaces for the farmer to insert his rainfall and several columns to enable daily deficit calculations to be made for a number of paddocks. Alternatively, the weekly deficit at Winchmore for a non-irrigated and irrigated area, compared with the corresponding figures for the same date in the preceding season, was published for many years in the farming pages of 'The Christchurch Press' as a general guide to farmers.

In view of the simplicity of the Thornthwaite estimation of P.E. and its proven application to the estimation of irrigation requirements, it is used in this study to describe the chronological sequence of agricultural drought in Canterbury. The use of Thornthwaite's P.E. estimation in this context is to provide a general and comparative framework within which to study the spatiotemporal development of artificial water supply in Canterbury. Thus it was felt that monthly data would be sufficient to illustrate the seasonal variations in the climatic water budget.

CONCLUSION

The following chapters will discuss, the physical characteristics relevant to irrigation (Chapter Two), the historical development of rural water supplies for agriculture (Chapters Three and Four). Chapter Five will discuss the results of the climatic analysis, while Chapters Six and Seven will endeavour to relate the climatic data, along with other relevant factors to the development of artificial water supplies.

CHAPTER TWO

CANTERBURY: PHYSICAL

GEOLOGY

Four distinct physical regions can be recognised within the Province. Furthest inland lies the range and basin country of the Southern Alps with its bordering foothills. To the east of this region are the downland, plain, and peninsula regions. The most extensive areas of downland occur south of the Rangitata River, with the greater part lying between sea level and 300 m above sea level. This area consists of uplifted, faulted and folded tertiary marine deposits; mainly limestones, sandstones and greywacke gravels. Greywacke hills occur locally within the downs and extend westward to join the main greywacke chain of the Southern Alps.

Seaward of the downlands region lies the Canterbury Plain. The Plain, averaging 50 km in width and with an area approaching 8,000 square kilometres, has been built on the framework of the large piedmont gravel aprons combined with glacial outwash transported by rivers from the Alpine ranges and foothills during the fluctuating conditions of Quaternary time.

Groundwater on the plains has long been a source of stock, domestic, public and irrigation supplies, and because of its economic importance has been monitored and studied by the N.Z. Geological Survey since 1947.

The degree to which direct rainfall infiltration on the plains on the one hand, and influent seepage from rivers on the other, have contributed to groundwater has been argued by successive geologists for nearly a century (Wilson, 1973).

Wilson is of the opinion that recent experiments, notably that reported by Dalmer (1971), imply that the recharge of groundwater under the Canterbury Plains does not depend only on infiltration from the annual rainfall on the plains (750 mm average), but is supplemented by rivers rising in the Alps and with a total catchment in excess of 13,000 km^2 where the average rainfall is approximately 1,700 mm. Groundwater availability is therefore linked with river behaviour, perhaps depending especially on the distribution of routes of influent seepage.

The volcanic rocks of Banks Peninsula are dominantly andesitic flows, tuffs and agglomerates. Springs encountered during the excavation of both Lyttelton tunnels, and occurring at the surface at several points on the peninsula, show that some beds, probably jointed zones in lava flows, and intergranular spaces in clastic and pyroclastic beds are aquifers. The location of groundwater reservoirs is unpredictable however, and no high yielding wells are known on Banks Peninsula.

Physiographic factors such as the situation of the soil in the landscape and its surface contours may be a limiting factor in irrigation development. These factors combine, along with the geological makeup to make Banks Peninsula largely unsuitable for the development of irrigation and this area will not be considered further in this study.

Such physiographic features, especially the surface relief, make large areas of the downlands and foothills, unsuitable for present large scale irrigation, even though large areas of soils formed on the loess-covered downlands, at present farmed moderately intensively, cannot be used to their maximum productive capacity because of seasonal drought (Raeside, 1971).

OUTLINE OF HYDROGEOLOGICAL PROVINCES

In Figure 2.1, Wilson's (1973) work is reproduced. It can be seen that the plains have been divided into two lateral segments by the geological boundary between glacial outwash gravels and post-glacial alluvium. Pre-Quaternary rocks of the foothills and of Banks Peninsula are also mapped.

The plains are further subdivided into transverse segments, each genetically related to a parent river. These segments are of hydrological significance because influent seepage from any river is more likely to remain in the permable deposits of the river's own sequence of fans than to cross to neighbouring sectors.

The boundaries between fans of adjoining rivers are based on the topographic expression of each fan. Finally, a coastal sector of confined groundwater to the north and south of Banks Peninsula is also mapped using accumulated borehole data.

Thus, Wilson (1973) maps five provinces:

1) Pre-Quaternary rocks of the foothills and Alps;
2) Volcanic rocks of Banks Peninsula;
3) Unburied glacial and peri-glacial outwash gravels of the plains;
4) Postglacial alluvium and buried outwash gravels of the coastal and central plains;
5) The artesian area near Banks Peninsula.

Provinces 3) and 4) are subdivided according to river of origin.

THE SIGNIFICANCE OF GEOLOGY IN IRRIGATION PLANNING

Wilson (1973) records wells yielding from 400 to 2,000 l/min. as being common throughout the area mapped as postglacial alluvium in Figure 2.1. Specific capacities of similarly constructed 15-cm-diameter wells range from 550-3,000 $m^3\ d^{-1}\ m^{-1}$, values tending to rise from west to east.

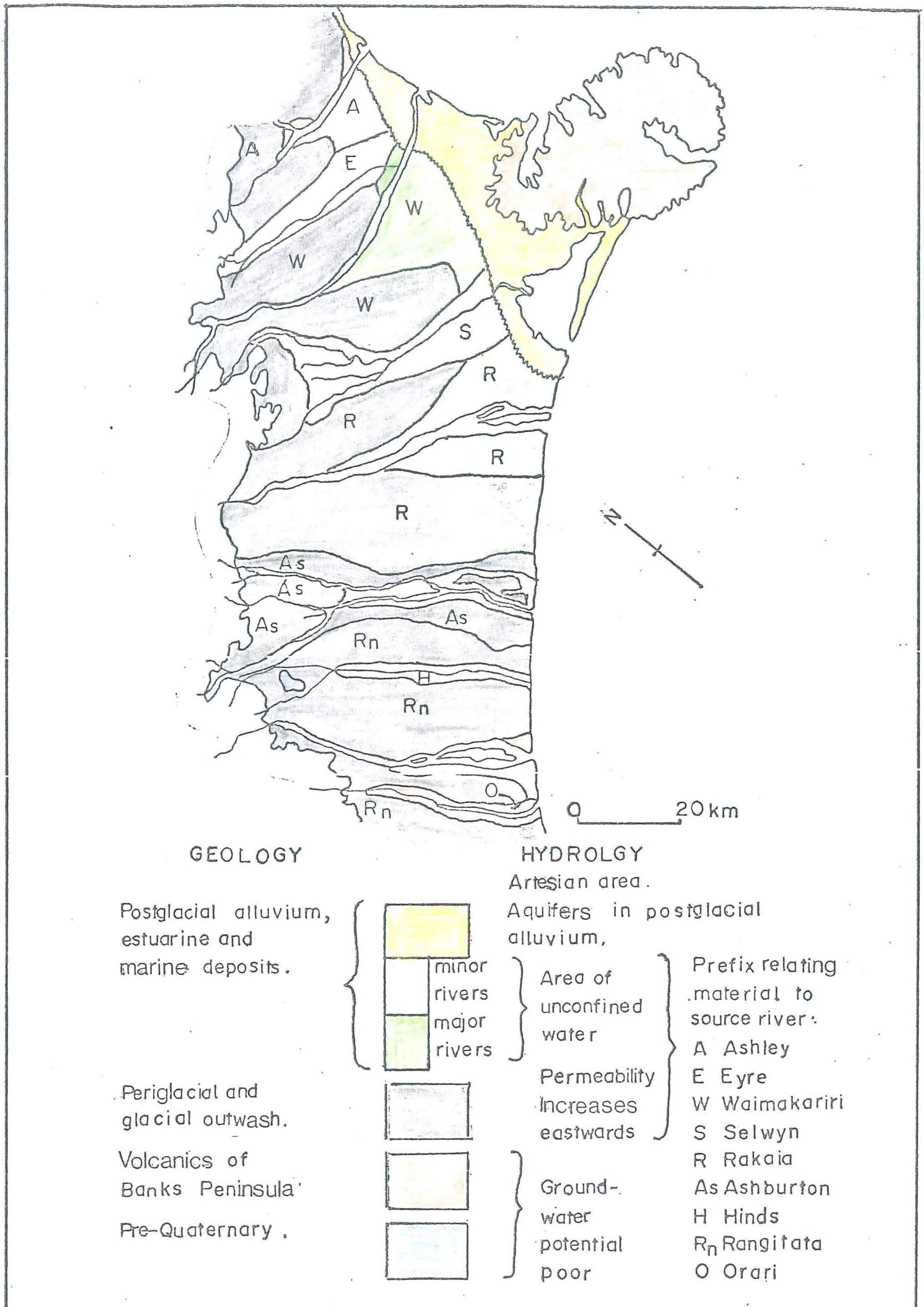


FIGURE 2.1: THE HYDROGEOLOGY OF THE CANTERBURY PLAINS

(Source: Wilson, 1973)

Transmissivity varies rapidly in lateral and vertical directions, and it is hypothesized that highly permeable aquifers might represent old stream channels, while poorly permeable aquifers are overbank deposits.

In the area mapped as glacial outwash (Figure 2.1), yields are an order of magnitude smaller ranging from 10 to 100 litres/minutes. Moreover, the higher yields occur only in a few places near the boundary between glacial and postglacial deposits. Thus, according to Wilson, the geological boundary between glacial and postglacial beds broadly separates areas where irrigation from groundwater is feasible from areas where it is not.

CLIMATE

Two locational factors are preeminent in determining the climate of Canterbury. First, it lies in the path of the westerly winds that prevail in the latitudes of the 40s, and second, it is on the lee side of the Southern Alps, which average 1,800-2,000 metres in height. This creates a rain-shadow effect over the area - moist air-streams loose their moisture on the western side of the ranges - consequently rainfall on the plains is low compared with the majority of the rest of New Zealand, and ranges from 500 mm annually on the southern most plains to between 600 and 750 mm on the downs, with a few places in the hills receiving 850 mm and more per annum. On the plains the rainfall increases westwards, gradually over most of its width but more rapidly near the hills.

Summer temperatures can frequently be high, while the mean monthly temperatures range from 5°C in July to 15°C in January, and frequently exceed 20°C. Winds are particularly important in Canterbury and can play a significant role in agriculture, especially in the summer months when the strong warm winds create much drier conditions than temperature or rainfall figures may indicate. The north-west wind is more frequent and stronger inland than at the coast, where the north-easterly is the most frequent. The nor' wester is a hot, dry wind of a Föhn type which gives rise to conditions of low humidity and occasionally very high temperatures.

Rickard (1960) records monthly rainfall figures as showing a slight summer maximum, 56% of the annual total falling from September-March. However, rainfall deficiencies during these months may be serious for primary production, this is especially true for the period of spring growth. By his definition of agricultural drought, Rickard estimated that over a period of 44 seasons, 90% of the days of drought occurred in the September-March period. He also found (at Winchmore Irrigation Research Station, near Ashburton) that in three out of every four seasons drought conditions could occur for 40 days or more, and for two of these four seasons drought conditions could last for over two months.

SOILS AND THEIR SUITABILITY FOR IRRIGATION

The climate of the region is reflected in the moisture regimes of the soils. From a practical standpoint the most important aspect of soil moisture regimes are the duration of periods when soil moisture is below wilting point or above field capacity, and the season when this occurs.

Much of the Canterbury soil has been formed on gravelly alluvium or loess derived from the indurated greywacke and schist of the mountain catchments. Weathering of the alluvium has taken place to a moderate extent only. These outwash areas comprise nearly 4,000 km^2 of the plains, and for intensive farming would require at least 500 mm of supplementary moisture. This represents 500,000 m^3/km^2, or 0.05 $m^3 s^{-1} km^{-2}$ applied continuously through a 120-day growing season.

This quantity is not available from explored aquifers. The alternative is to use surface water, but there are some periods during most growing seasons when river flows would be unable to meet the need.

Free draining sandy loams and silt loams are the soils most suited for irrigation (Raeside, 1971). They are also the soils best suited for cropping under dryland farming. Silt loams are extensive where the alluvium has a mantle of loess, while sandy loams are less extensive. Clays and clay loams cover only a small area, and are generally regarded as being less suited for irrigation because of their slow drainage. Small areas of these soils are, however, well suited for market gardening but, because of summer drought, they can reach their maximum levels of production only when irrigated.

Although the alluvium of the fans and terraces of the major rivers is gravelly and permeable, in some places it has received a thin mantle of late Pleistocene and post-Pleistocene loess. Some of this loess has been washed into the uppermost 30-50 cm of the gravels, and greatly improved their physical properties. Drainage through the soil is thereby reduced, its structure is improved, and its suitability for irrigation is greatly increased. Soils with such a cover of loess are widely distributed on the higher parts of the Canterbury Plains.

CONCLUSION

The discussion of the climatalogical and hydrogeological factors of the Canterbury Plains indicates the need for the provision of an assured water supply. This is reflected in the type of farming operation that has evolved in Canterbury. A system of dryland farming has evolved which, on the downs and plains, is predominantly mixed crop - livestock farming. On the drier areas of the downlands and light lands of the plains a greater percentage of sheep, in relation to cropping, are grazed with a correspondingly higher carrying capacity per hectare; 17 on the light lands, and 15 on the downs.

The fact that until recently the light lands carried less than four sheep to the hectare indicates the rapid development of these areas, made possible by the modern farm management techniques. Even today, on some of the more marginal areas (the present flood plains and river-beds) a pioneering attitude survives as younger farmers break in the land with the aid of modern equipment, fertilizers and the hope of irrigation.

Although the overall need for irrigation is reflected in the agricultural system, the present efficient dryland system may, through farmer's attitudes, provide a constraint upon irrigation development. This aspect will be discussed in more detail in succeeding chapters.

Assuming, however, that the climatological and hydrogeological factors create a need for irrigation, the suitability of the region for irrigation needs to be considered. Figure 2.2 summarizes Raeside's (1971) work, in which a soil survey of irrigation suitability in Canterbury endeavours to recognize the importance of both the soil type and its physiographic location. Thus, it can be seen that large areas on the plains are suitable for irrigation development, while the downlands provide less suitable physiographic conditions for such development.

SUMMARY

A discussion of the physical features of the Canterbury environment; geology, hydrogeology, climate and soil type is presented. It is suggested that the combination of these factors may make irrigation a viable solution to agricultural problems encountered in parts of Canterbury.

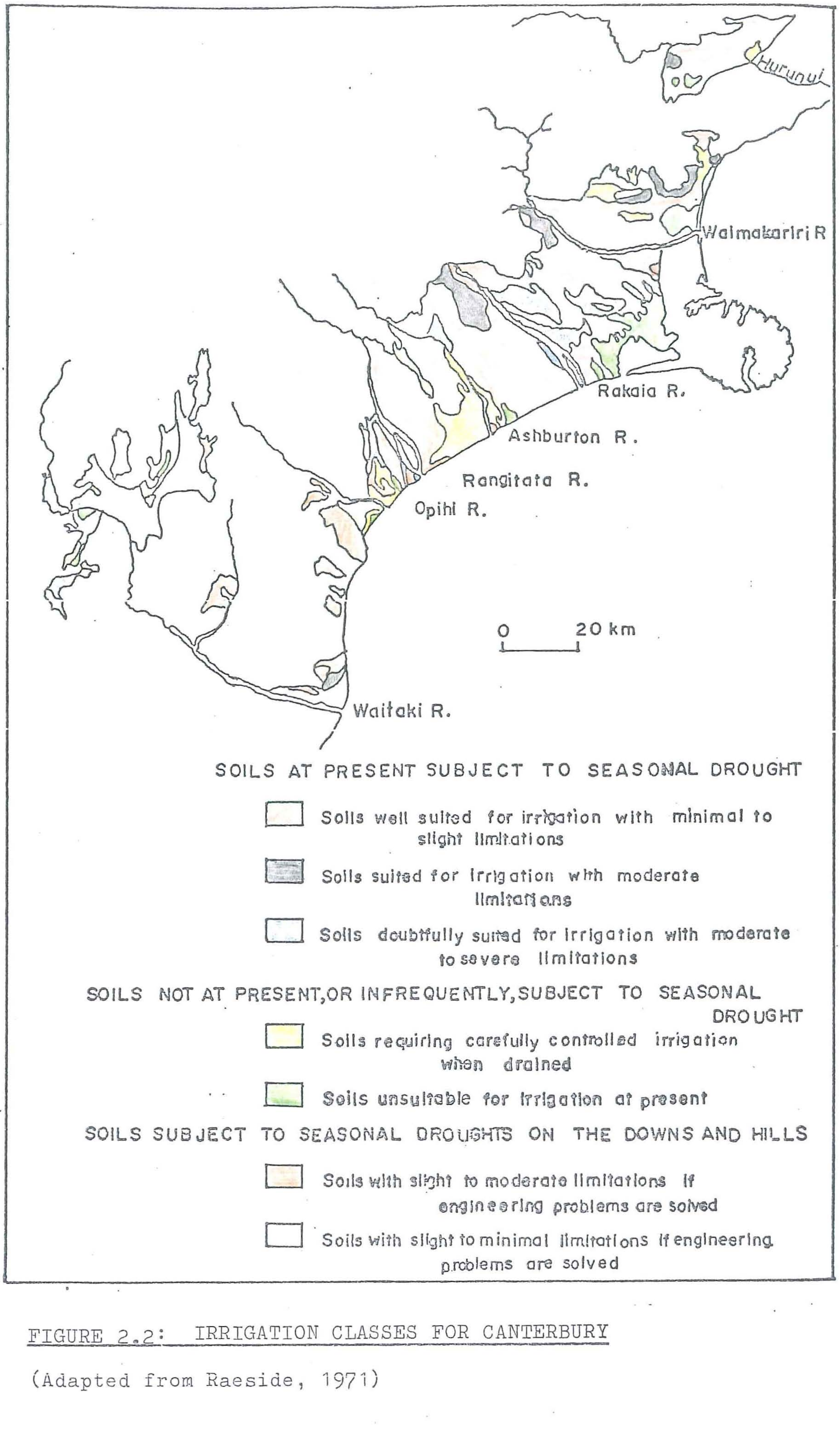


FIGURE 2.2: IRRIGATION CLASSES FOR CANTERBURY

(Adapted from Raeside, 1971)

CHAPTER THREE

ARTIFICIAL WATER SUPPLY ON THE CANTERBURY PLAINS BEFORE 1930

GENERAL

Many writers have written on aspects of the history of irrigation development on the Canterbury Plains, and some (Paul, 1945; Leadley, 1952; Fitzgerald, 1970) have attempted more comprehensive reviews.

This chapter summarizes developments up to 1930, a period in which small pioneer schemes of private individuals were replaced with, and in some instances, integrated into larger schemes organized at the County level.

In studying the available historical literature, a problem arises in differentiating between irrigation per se and the development of races for stock water. Some authors (Andersen, 1916; Hereford, 1902; Fitzgerald, 1970) do not differentiate between irrigation and stockwater. For example Fitzgerald (1970) dates the beginning of Canterbury interest in irrigation as occurring in 1865. Other authors (Leadley, 1952; Scotter, 1972) present no information relating to the development of irrigation at this time, but do, however, cite examples of early experimentation with stock water races around this time.

There is also disagreement between authors on the exact date when irrigation began to appear as opposed to races purely for stock water. Therefore, before reviewing the historical development of irrigation it would be pertinent to first examine the role of stock water races.

STOCK WATER RACES AND THE BEGINNINGS OF IRRIGATION

The distinction between irrigation and stock water lies in the function performed; the original and dominant function of water races was to provide an adequate and reliable supply of drinking water for stock; irrigation channels, on the other hand, supply water which is spread over the land to promote plant growth. Thus, water races, are to counteract the lack of surface water, and irrigation channels the lack of soil moisture.

Scotter (1965) contends that the settlement farms established by the Lands and Survey Department in the 1930s saw, "true irrigation, as distinct from the supply of water for stock, at last being developed." Although irrigation had been proposed almost as soon as water races were mooted it was not attempted until 1886, except for some surreptitious irrigation from the stock water races (Scotter, 1965, 1972). It is apparent that until this time the systems developed were primarily for the supply of stock water: although constantly referred to as irrigation. References to irrigation occurring in this early period (e.g. Hereford, 1902; Andersen, 1916; Brown, 1940) must therefore be viewed with suspicion.

Successful inauguration of stock races with insignificant loss from percolation certainly gave impetus to the desire for irrigation, and in 1886 a comprehensive scheme taking water from the Rakaia for irrigation and stockwater was proposed by C.E. Fooks (Leadley, 1952).

In January 1886, the Ashburton County Council first discussed irrigation schemes for the County, prepared by the county engineer, W. Baxter. It was proposed to irrigate five blocks of land with a total area of 160,257 hectares at a cost of $82,454 (Canterbury Times, May 11, 1886).

In 1891, Baxter proposed schemes; to irrigate Ashburton-Rakaia land by water from the Rakaia River that was to be diverted through a tunnel (13.7 Kilometres long) commencing near the gorge bridge; to augment the South Ashburton flow by tapping Lake Heron; to irrigate land north of the Rangitata by tapping the river lower down than at the present intake (Brown, 1940).

None of these schemes was ever put into operation, however, there were successful experiments including an irrigation farm. In March, 1887, the Ashburton County Council decided to undertake experiments on a 36 ha block at Elgin in the Wakanui district. In conjunction with this decision, the Council commissioned the writing of a book "Practical Irrigation", which was published in 1899. The book was an attempt to instill into farmers a desire to irrigate their land. The experiments were carried on till in June 1890 James Brown, in whose Wakanui riding the farm lay, successfully moved.....

> "that the benefits to be derived from irrigation having been clearly demonstrated, the Council is of the opinion that further experiment is unnecessary, and that all business of the farm be wound up by July, 31 next."
>
> (Guardian 5 June, 1890 in Brown, 1940)

And so it was by the end of August.

The comprehensive irrigation system developed, between 1893-1895, on the Australian and New Zealand Land Company's Action run was probably the most important Canterbury scheme at this time. It effected a great increase in productivity - 162 hectares were watered annually by what is now called 'wild flooding', and the production of wheat increased from 2.8 to 5.6 bushels the hectare (N.Z. Country Jl, Vol. 22). However, once the run was broken up, in 1903, the races were relegated to stock supply and the intake was enlarged to become part of the County Council stock water race system.

PRIVATE DEVELOPMENTS

The origins of the network of stock water races which serve the Canterbury Plains, and ultimately the large-scale irrigation schemes of the last 50 years, lie in the private experiments conducted by early mid-Canterbury runholders.

By the end of 1852 almost the entire Canterbury Block had been taken up by pastoral runs, but effective use of the whole area was hampered by the lack of stock water. Even though large volumes of water are discharged by the large Canterbury rivers from their seaward margins, the lack of tributaries once they leave the hills means the plains are deficient in surface water.

The first recorded construction of stock water races in Canterbury occurred in 1863 on the Ashburton Station, this was followed a year later on the Wakanui Station where a short channel was cut from the river for stock supply and use about the house (Scotter, 1972).

These schemes are summarized in Table 3.1. Three of them will be discussed at length as they have had a good deal of influence in determining the type of artificial water supply which was to become dominant on the plains.

In 1867, Foster Nixon, the manager of Alford, engaged C.E. Fooks to lay out a race of 2.4 km between a small creek and some dry paddocks. Insufficient water was available, however, except for a little irrigation about the house (Leadley, 1952).

Charles Reed visited Alford on several occasions, and in 1869 built a race 8 km in length to carry water from the Ashburton River into the centre of his property, Westerfield. Later that same year the length was increased to 19.3 lm, and he tapped neighbouring creeks to irrigate his orchard and home paddocks (Lyttelton Times, August 2, 1871).

Reed's object was to take water from the south branch of the Ashburton River, carry it across his paddocks in open races taking off leads at various places to water the lower portions of his estate, and discharge the races into the Hinds River. Owing to Reed's death this scheme was never completed, but a considerable network was evidently constructed (Table 3.1). Leadley (1952) justifiably comments, "it is quite clear that the success of the Westerfield races did much to encourage other runholders to construct similar improvements". Including, obviously, Duncan Cameron at Springfield, across the Ashburton River from Reed.

The Cyclopedia of New Zealand awards Duncan Cameron the honour of being 'the first to establish a systematic water supply on the dry but otherwise fertile lands of Central Canterbury' (Cyclopedia of New Zealand, III, p. 801). It was here on Cameron's property of Springfield that the most important private water race development took place. Cameron took over the management of the property in 1869, and realising that the lack of dependable water supply was the chief handicap to the station's assured prosperity he set out to remove this handicap. Cameron had inspected the Westerfield races and was satisfied that a similar system, on a larger scale, would solve his problem. During the early 1870s he built 6.4 km of race, and in 1876, acting as his own engineer, he constructed 20.9 km of open channel from an intake in the hills. This experiment proved so successful that, by 1880, he had 64.3 km of race running to all parts of Springfield.

It was the scope and reliability of Cameron's races which made them so important - all the year round they carried sufficient water for the 8,498 hectares of Springfield and enough to supply neighbours as well; and, moreover, the races ran over widely different types of soil without significant loss from percolation.

Leadley (1952) comments that the success of Reed's and Cameron's open races was the first decisive factor in determining the type of artificial water supply which was to become dominant on the plains.

Table 3.1: PRIVATE WATER RACES

Date of Completion	Scheme	Length of race(s) or area served	Source
1863	T. Moorhouse: Ashburton Station		Leadley, 1952
1864	Wakanui Station		Leadley, 1952
1867	F. Nixon: Alford	2.4 km	Leadley, 1952
1869	C. Reed: Westerfield	19.3 km	Leadley, 1952
	J. Hall: Hororata		Mote, 1974
1869	Ringwood		Leadley, 1952
1869- 1876- 1880	D. Cameron: Springfield	6.4 km 20.9 37.0 64.3 km	Scotter, 1965 1972
1878	McIlraith: Mt Hutt		Leadley, 1952
1878	J. Hunt: Wakanui		Leadley, 1952
1895	Acton Estate	162 ha	Scotter, 1972

COUNTY COUNCIL SCHEMES

Clearly the use of water for irrigation was in the minds of some men of the times, and the subject was on several occasions before the public and even the Provincial Council during the late 1860s.

In 1871, Colonel Brett, of Kirwee, persuaded the Provincial Council to engage C.E. Fooks to report on the possibility of irrigating the Malvern district between the Waimakariri and Selwyn Rivers. A sum of $50,000 of public money was allocated, however, the report published in 1872 produced a good deal of controversy, and construction did not begin until 1876 after two subsequent revisions of the original proposal.

The work was commenced in August 1876, with construction of headworks at the Kowai River, consisting of a concrete dam 91 metres long across the river. The Malvern water race was officially opened on December 1877, and was the first made by any authority in Canterbury.

By this time the Selwyn County Council had been constituted, and the completion of the water race properly came within its province. At first the Council demurred at taking over the work, preferring that it be completed by the General Government, but this reluctance having been overcome, the Council formally accepted control of the race as from September, 1878.

By mid 1880 the race had been completed to Waddington (Figure 3.1), where it divided into 2 main branches, one continuing to Kirwee and the other along the main road to Darfield. Construction was comparatively easy, and by the end of 1880 contracts had been let for the completion of the race to Kirwee and Darfield, where the water reached in due course, while in January of the same year a

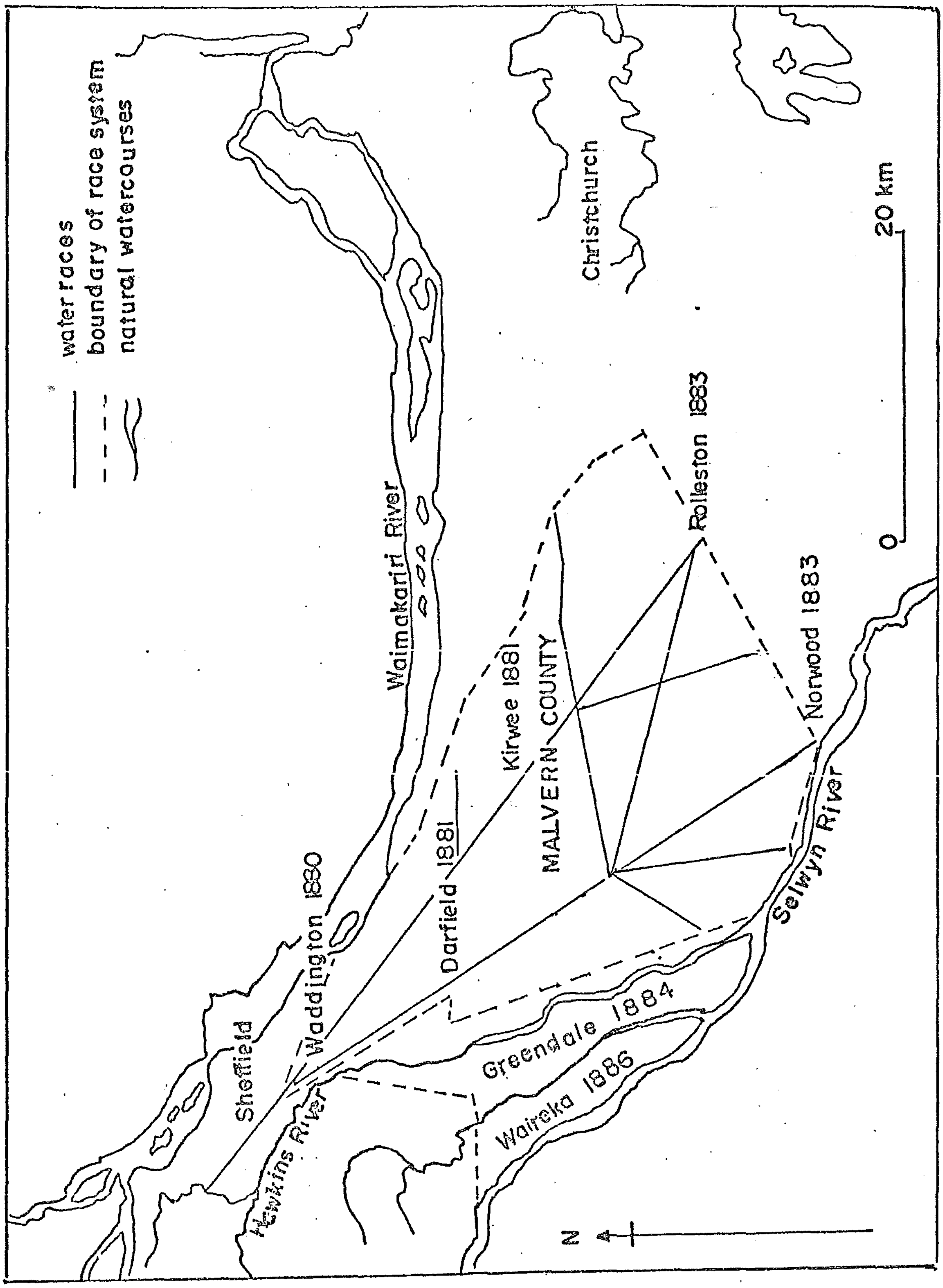


FIGURE 3.1: THE SELWYN COUNTY COUNCIL STOCK WATER RACE NETWORK, 1871-1886

(Source: Ritzo, 1894)

second main race was opened from the Hororata River, which served 28,328 hectares (Scotter, 1965). From then on reticulation of the district was rapidly extended. The expansion of the system is summarized graphically in Figure 3.1.

By the end of the 1880s it had become apparent that the capacity was not sufficient - expansion of the system therefore called for an additional supply of water. By the end of 1890 an additional race taking water from the Waimakariri near the gorge bridge was constructed at a cost of $8,000. However, it was never satisfactory owing to the high cost of maintenance and loss of water by percolation (Scotter, 1965).

As a result of the floods which swept through the province in March 1902, serious damage was done to the Kowai dam, which eventually led to its abandonment and the construction of new headworks.

In 1908 the Waimakariri gorge race was put out of action by the collapse of the fluming at Dean's gully, with serious washouts along the line of the race.

On the division of the Selwyn County in 1911, the water races were handed over to the newly constituted Malvern County Council. The area served by the Malvern water races does not extend beyond the Hawkins River, and separate water race systems were provided by the then Selwyn County Council for the Greendale and Waireka districts in 1884 and 1886 respectively (Figure 3.1).

In North Canterbury a system based on an intake from the Waimakariri at Brown's Rock with main races towards Rangiora, East Eyreton and Bennets, distributing 2,273,000 litres a day was opened in 1896 by the Waimakariri-Ashley Water Supply Board.

The Ashburton County Council was formed in 1876, and Scotter (1972) suggests that the prospect of organising a county-wide water supply was probably the main reason for the Council's acceptance in 1877 of the full powers given it by Parliament. Conditions appeared to favour prompt action. A meeting of ratepayers at Rakaia in January 1878 petitioned the council to undertake a scheme for supplying the area between the Ashburton and Rakaia Rivers with water. The need for a supply appears to have been generally recognised - as one farmer said,

> "A complete system of irrigation is required to make land productive, as the want of water for ordinary purposes must always be felt, where it is difficult to obtain."

(Ashburton Mail, February 12, 1878; Scotter, 1972)

Farmers considered that, the provision of races on the upper fans was uneconomical for individual landowners, and as funds were available from the county's share of land sales, the local authority was in a position to finance a co-ordinated scheme.

Work on the county stock water system did not begin, however, for another two years when the council agreed that a dam and a weir should be built at the intake on Pudding Hill stream, 10 km north-west of Methven, which was opened on 31 January 1881, along with a 51 km open channel as far as Seafield (Figure 3.2).

Almost immediately, the council received deputations and petitions from Hinds and Rakaia, one asking for a similar scheme for the south of the country, and the second complaining that what had been done was insufficient. Wakanui farmers wanted permission to draw off water from the Ashburton River. By the middle of the year 100 km of race had been completed, 50 km were being constructed and tenders were let for 40 more.

Soon afterwards, in April 1882, large headworks were opened on the South Ashburton some four miles above Mt Somers township.

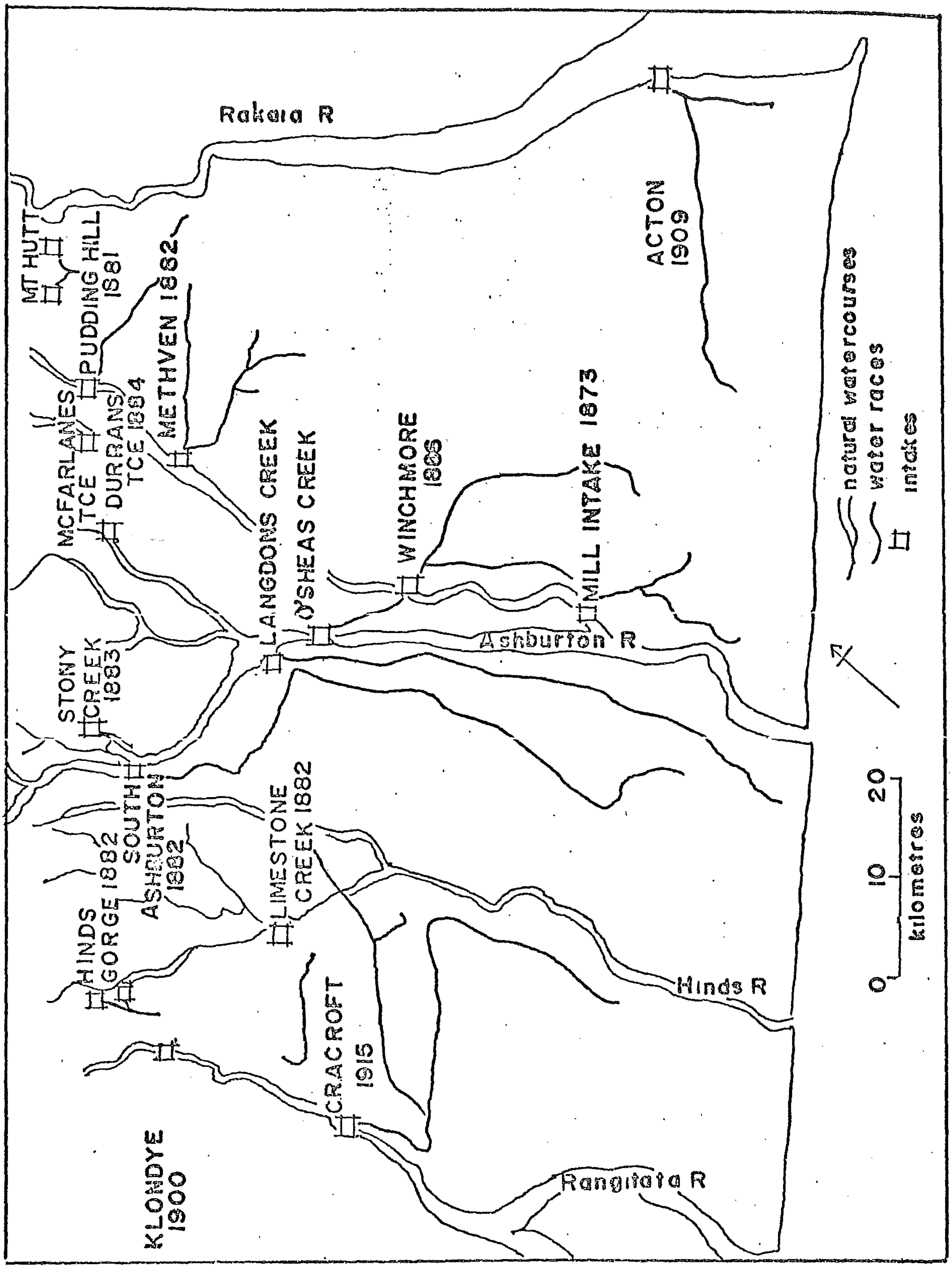


FIGURE 3.2: ASHBURTON COUNTY COUNCIL STOCK WATER RACE SYSTEM (1873-1915)

(Source: Leadley, 1952)

A few months later, smaller intakes in the Hinds Gorge and on Limestone Creek came into operation. A supplementary race was cut from the North Ashburton to boost the Pudding Hill supply. By then there were 756 km of county races at a total constructional cost of $20,400 (Leadley, 1952).

By the end of 1903, the Ashburton County Council had constructed 2,253 km of race, with intakes, at a cost of $68,000 and was supplying 242,814 hectares of land with water.

In 1909, the 19 km 'Action Irrigation Canal' was opened, followed in 1915, by the lower Rangitata intake at Cracroft, which was the last of the major headworks. In the words of the contemporary editor of the Ashburton Guardian (May 25, 1915, quoted by Scotter, 1972) - "If the Cracroft scheme is not the coping stone of the system, it comes very near to being so". This editorial comment was a fairly true expression of the completeness of the system. Since 1915, a few smaller intakes have been constructed and the length of branch races continued to increase - by 1928, a total length of 3,540 km, to which another 254 km was added by 1942.

The achievements of the Ashburton County Council were certainly not paralleled elsewhere in Canterbury, where schemes were on a smaller scale. In South Canterbury it was urged as long ago as 1872 by stock inspectors and others that the obstacle of lack of water to increased production must be overcome. Gillispie (1958) records that in November 1872, W. Rolleston, when outlining some proposed legislation to members of the Canterbury Provincial Council, recommended that a water race be constructed from the Pareora River to Timaru and added,

> "Should the construction of this water race prove successful, there is good reason to believe it would lead to the construction of similar races over portions of the plains which are now unavailable for general settlement for want of water."

The race was completed in 1874.

At a meeting of the Geraldine County Council held on the 6 September, 1882 it was proposed that a scheme similar to the one that had proved successful in the Ashburton County be constructed for irrigating the Orari Plains, and the Levels and Waitohi districts. The cost was $64/km, however, public opposition to the cost caused its retrenchment. In April of the following year a reduced scheme was submitted for irrigating part of the Levels flats from an intake on the Opihi River. The area to be served would not exceed 3,238 hectares. The cost including all expenses would be $4,080. This and other schemes were adopted throughout South Canterbury, particulars of the races by 1916 in the various counties are given in Table 3.2.

Table 3.2: DETAILS OF SOUTH CANTERBURY SCHEMES

County	Area Watered (ha)	Kilometres of races	Total Cost $
Geraldine	28,819	418	18,020
Levels	7,689	114	11,000
MacKenzie	3,804	56	3,870
Waimate	9,469	201	12,042
	49,781	789	44,932

(After Andersen, 1916)

SUMMARY

By 1930, considerable areas had been provided with a system of water races in the Selwyn, Oxford and Ashburton counties, with a much smaller development in the four counties of South Canterbury. However, a considerable area of Canterbury was still without such systems. Particularly in the Northern and Southern extremes of the province, and an extensive area between the Selwyn and Rakaia Rivers.

The rate of development was quite rapid once schemes were adopted by Councils. Data for the Ashburton County, which had the greatest development is graphed in Figure 3.3, which shows the rapid growth rate of the Council scheme.

Although many writers talk of irrigation, the development at this time was primarily stock water races. Several experiments in irrigation occurred, but no major schemes were developed during this period.

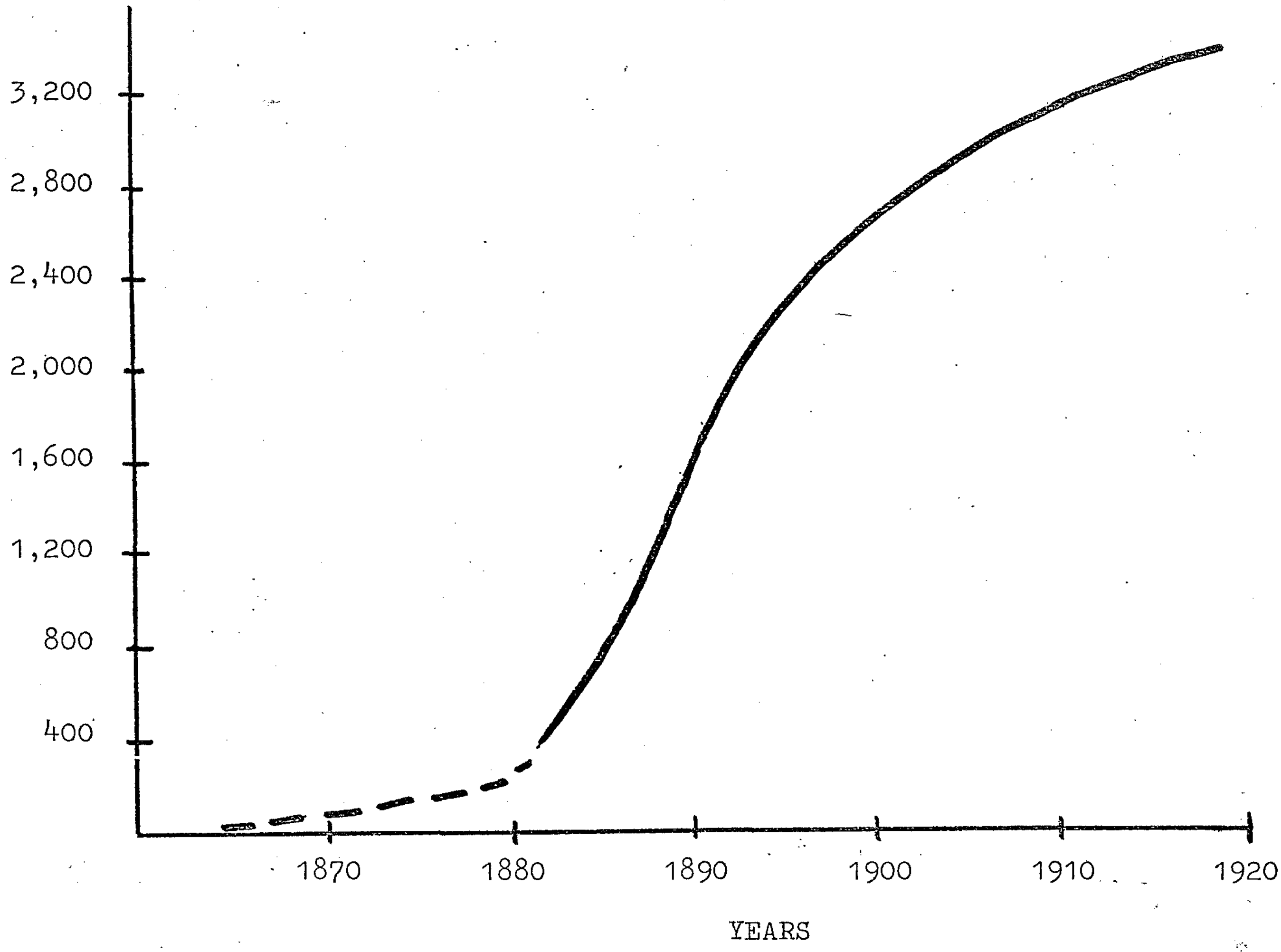


FIGURE 3.3: RATE OF WATER RACE DEVELOPMENT IN ASHBURTON COUNTRY

- - - Mainly Private

——— Mainly Council

CHAPTER FOUR

IRRIGATION SINCE 1930

GENERAL

Interest in irrigation was largely dormant during the early decades of this century. The Ashburton County Council, however, continued to slowly extend its stock water races - adding 254 km between 1925 and 1942. Thus Figure 3.3, which graphically depicts water race development in Ashburton County, can be extrapolated to reproduce the classic innovation curve. Once again, as had been the experience since the beginning of the system, these races made possible a certain amount of surreptitious irrigation during spells of dry weather (Scotter, 1972).

In May 1931, irrigation committees were set up by the Canterbury Progress League and the Canterbury Chamber of Commerce (Minutes of the Progress League 12 May 1931). The result was an irrigation farm established by the Lands and Survey Department, with assistance from Lincoln College, on Crown land at Seafield. The Department of Agriculture had also started two trials in the Oxford district, and also at Hororata, Motukarara and Southbridge (Minutes of Canterbury Progress League 1 Feb. 1933).

In October 1933 the Ashburton County Council, other local bodies and departmental representatives discussed plans for the irrigation of the plains. Three important projects emanated from this meeting: a soil survey; a farm management survey; and a number of irrigation schemes were planned and commenced by the Ministry of Works irrigation engineer (M.O.W., 1945).

THE SCHEMES

It can be seen from Table 4.1 and Figure 4.1 that there are ten irrigation schemes presently operating in Canterbury, the Waiau Plains scheme under construction, and a further nine are proposed.

The first schemes to be opened were in South Canterbury; the Redcliff and Levels Plain schemes, where water became available in 1937. The Redcliff scheme draws water from the Waitaki River, which is distributed through 30.5 km of races. From Figure 4.2 it can be seen that by 1973 28% of the area had been border-dyked. The water for the Levels Plain scheme is drawn from the Opihi River and distributed through 85 km of races. Here 17% of the area had been border-dyked by 1973 (Fitzgerald, 1974).

It is apparent that on these schemes farmers were reluctant to have their land prepared for irrigation. Despite the efforts of the Department of Agriculture, and the incentives offered, farmers were largely unconvinced that irrigation would be in their best interests. As well as capital investment and management problems, irrigation entailed a considerable change in work routines, which lead to the South Canterbury farmers viewing "irrigation farming and slave-labour as being one and the same thing"(The Press, June 6, 1930).

In 1937 construction also began on the Rangitata Diversion Race (Figure 4.1). Water is diverted from the Rangitata River along a 70 km race, almost eight metres wide and three metres deep. This diversion race follows the 609m contour at the top of the plains and the surplus water is run into the Rakaia River. From this diversion race it was planned to channel water into three separate irrigation areas; Valetta-Tinwald Scheme, Ashburton-Lyndhurst Scheme, and the Barhill Scheme. A further scheme was to be served independently; Mayfield-Hinds from the Rangitata River.

TABLE 4.1: CANTERBURY IRRIGATION - EXISTING SCHEMES
(As at February 1976)

Scheme	Start of Construction	Completed	Size (Ha)
Redcliff	1935	1936	2,465
Levels Plain	1935	1937	4,860
Ashburton-Lyndhurst	1935	1945	25,920
Mayfield-Hinds	1937	1948	34,420
Valetta Farm Settlement	1955	1958	7,050
Morven-Glenavy	1972	1974	12,140
South Rakaia		1974	1,011
Waireka Downs		1976	485
Greenstreet	1973	1975	2,711
North Rakaia		1976	1,618

TABLE 4.2: AREA BORDER-DYKED ON THE CANTERBURY IRRIGATION SCHEMES

	Area Bordered (ha)				
Season	Ashburton-Lyndhurst	Mayfield-Hinds	Redcliff	Valetta	Levels
1944-45	310.0				
1945-46	371.9				
1946-47	598.2				
1947-48	502.6				
1948-49	649.1	151.8	13.8		
1949-50	770.2	217.3	36.4	–	4.0
1950-51	622.4	198.7	25.5		24.3
1951-52	453.2	78.1	44.5		56.6
1952-53	447.7	115.0	0.0		53.9
1953-54	431.0	146.1	52.6		46.9
1954-55	442.7	308.8	56.3		34.4
1955-56	479.2	502.6	51.0		77.7
1956-57	301.5	471.1	16.6	212.1	54.2
1957-58	285.7	250.1	0.0	324.5	18.6
1958-59	269.5	229.4	0.0	483.2	16.6
1959-60	283.3	198.4	19.0	527.0	6.5
1960-61	228.3	291.7	3.6	482.8	23.1
1961-62	132.7	297.0	6.1	314.8	14.2
1962-63	143.7	288.1	0.0	288.9	30.7
1963-64	191.0	292.0	13.6	249.7	24.3
1964-65	284.9	456.2	42.9	291.8	46.5
1965-66	283.1	359.6	117.5	176.5	31.6
1966-67	242.6	354.8	122.3	85.2	28.7
1967-68	170.9	220.3	83.4	42.1	21.9
1968-69	242.2	205.0	83.5	19.0	34.0
1969-70	285.1	364.4	110.1	64.4	16.8
1970-71	306.6	311.5	68.9	94.7	69.2
1971-72	342.0	436.4	5.3	143.1	141.9
1972-73	421.2	614.4	28.3	64.2	154.6
1973-74	415.3	824.6	0.0	85.7	106.7
Total	10,907.8	8,152.5	1,004.2	4,049.7	1,339.9
% of Total Area	42.08	23.70	40.74	57.44	27.57

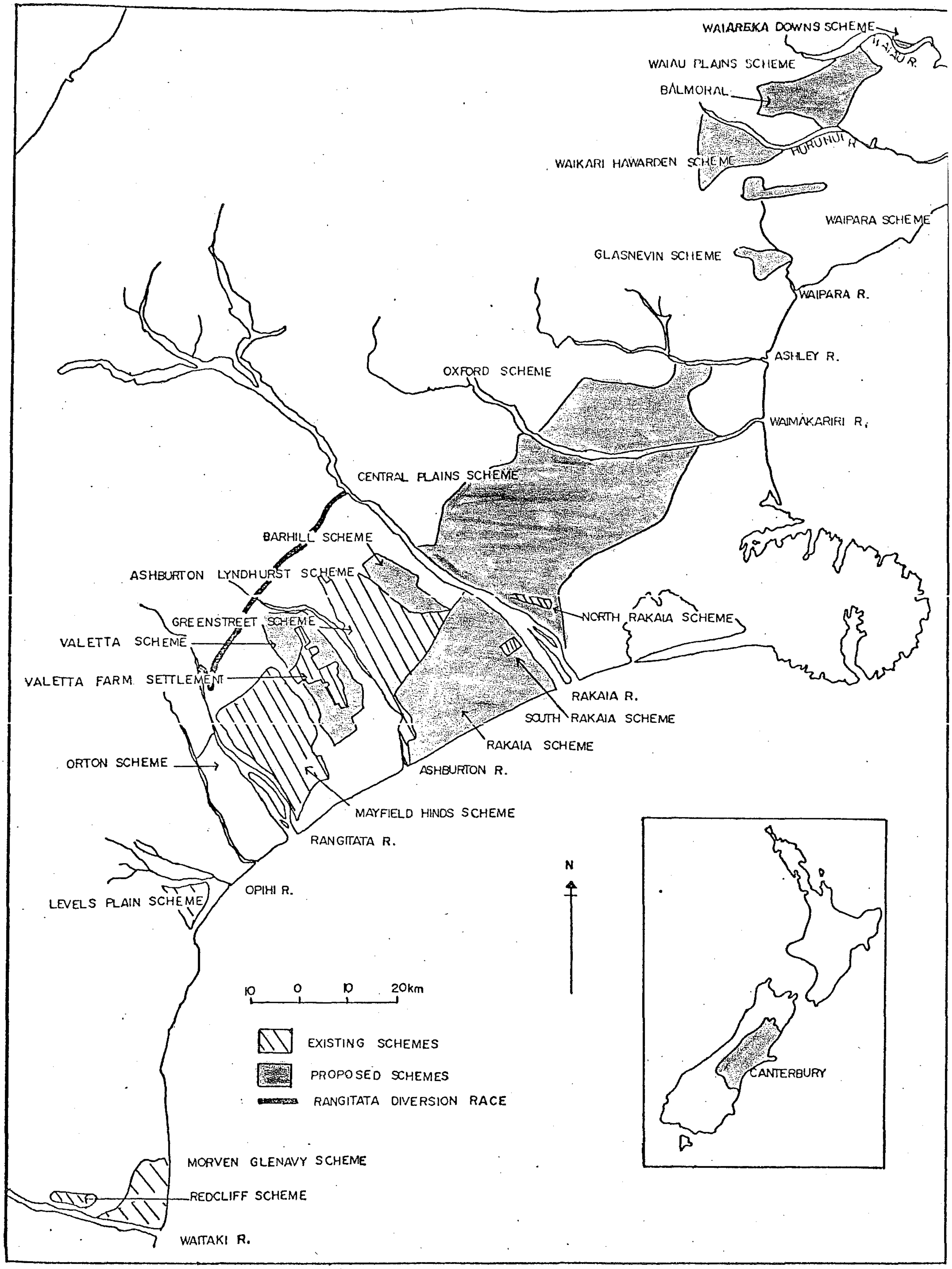


FIGURE 4.1: IRRIGATION SCHEMES IN CANTERBURY

(Source: M.O.W. 1976)

This plan was subsequently revised, and the Rangitata Diversion Race presently serves three schemes; Ashburton-Lyndhurst, Mayfield-Hinds, and the Valetta Farm Settlement - where water became available in 1944, 1948 and 1958 respectively.

As can be seen from Table 4.1, apart from the Valetta Farm Settlement developed by the Lands and Survey Department, no schemes were developed during the 50s and 60s. This curious lack of activity will be discussed at length in a subsequent chapter. Although there was little concrete development, the period from 1950-1970 was a period of activity and controversy - arising mainly from Government policy and preliminary economic investigations for future schemes.

During April 1954 the Government announced its policy on the establishment of new irrigation schemes in Canterbury. This provided that owners of 75% of the area had to be in favour and that a rating scheme would be used to cover scheme costs. In May 1955, the preliminary results of a survey of the Rakaia Scheme were made public. The cost of the scheme was estimated at $6,600,000. During the latter part of the year a ballot was held and the scheme rejected by 22,865 to 22,541 hectares. An analysis of the results showed that while large farms voted against the proposal, individual farmers voted 194 for and 85 against (Fitzgerald, 1970).

The Government became concerned that a minority could deny irrigation to the majority and subsequently a Parliamentary Select Committee on irrigation was set up to investigate all aspects of irrigation. In July 1959, the Committee made several recommendations on the administration and extension of irrigation. As a result of this an amendment to the Public Works Act was passed providing that in a ballot for an irrigation area a 60% majority would be needed and voting would be on the basis of one vote per farm.

During the 1960s preliminary surveys were made of the MacKenzie Basin and the Glenavy-Morven area, in 1963 and 1965 respectively. Associated with the latter investigation was the establishment of a pilot farm to study land preparation problems and to demonstrate irrigation (Fitzgerald, 1970).

In October, 1966 a public meeting of 60 irrigators and potential irrigators in the Ashburton-Hinds area formed an irrigation association. (The Press, Dec. 10, 1966). The meeting moved that the Interdepartmental Committee on irrigation should ascertain existing supplies of water and investigate future requirements. In late 1966, a new bill called the Water and Soil Conservation Bill, which made provision for the control of water to be vested in the Crown, was introduced into Parliament. The bill was eventually passed and came into force on 1 April, 1969. The Act provided for local water authorities to consider applications for rights to take water for various purposes including irrigation.

In March 1969 about 100 farmers from the Oxford area met to discuss irrigation north of the Waimakariri. A resolution was passed that three branches of the Federated Farmers (Oxford, Cust-West Eyreton, and Fernside) should undertake a preliminary investigation of irrigation possibilities (The Press, March 22, 1969). In October, the Ashley County Council considered a scheme to irrigate 160 hectares of orchards at Loburn. While in Darfield a meeting of 90 farmers formed a committee to ascertain support for irrigation in 40,000 ha south of the Waimakariri. The committee proposed to obtain reaction from 460 farmers to see if they were in favour of the Ministry of Works being asked to authorize an investigation (Fitzgerald, 1970).

In September 1969, the Minister of Works announced that a committee would be set up to inquire into ...

> "irrigation's place in the national economy, into conservation and allocation of water resources, into future management of existing government schemes and into promotion of new schemes including those run by local authorities and private persons as well as government schemes."

A report on the Committee's findings was subsequently published in July, 1971.

During the first half of the 1970s five schemes were completed (Table 4.1, Figure 4.1). The first was the Morven-Glenavy Scheme, which extends the Redcliff Scheme towards the sea, and commands an area of 12,140 hectares; with water supplied from the Waitaki River which lies to the south. A smaller scheme of 1,012 hectares in South Rakaia was also opened in 1974.

In 1974 the Water Resources Council had allocated certain priorities for major irrigation schemes in the Canterbury area. These priorities were:

1) Completion of the Morven-Glenavy Scheme,
2) The Waiau Plains Scheme,
3) The Lower Rakaia and Pendarves Scheme, and
4) The Central Plains Scheme (The Press, May 26, 1978).

The first priority, along with several smaller schemes, has been achieved (Table 4.1). In May 1978, the District Commissioner of Works, Mr P.F. Reynolds, confirmed that the Ministry of Works thinking was in accordance with the Water Resources Council priority rating. Thus, with the Waiau Plains scheme under construction, the Rakaia scheme will be the next major development in Canterbury, followed by the Central Plains Scheme (The Press, May 26, June 16, 1978).

WINCHMORE IRRIGATION RESEARCH STATION

In the early stages of construction of the Ashburton-Lyndhurst scheme it was recognised that those charged with the responsibility for instructing farmers must be able to obtain experimental data on practical irrigation farming in the area in order to demonstrate the benefits of water use to potential irrigators. For this purpose arrangements were made with a local farmer to irrigate 19 hectares using water from stock water races. Irrigation began on this block at Winchmore during the 1937/38 season (M.O.W. 1945).

This demonstration block was maintained for seven years until the irrigation scheme had been constructed, and showed farmers that irrigation when combined with recommended techniques of fertilising and stocking was capable of raising the carrying capacity dramatically. Stock units/hectare were increased from 2 to 14 while at the same time increasing the weight of wool and lambs. In addition the life of the pastures was substantially lengthened. Under established patterns of dryland farming with little or no fertiliser and low stocking rates, pastures had a life of no more than three years. Irrigated pastures, when well managed, were found to be in better condition after seven years than most two year old pastures on similar soils without irrigation (M.O.W. 1945). So important did the authorities consider the role of demonstration and constant research into irrigation techniques that in 1946 a 308.5 hectare block of land was purchased in the centre of the irrigated zone for the establishment of an Irrigation Research Station.

The scope of work undertaken at present by the Research Station lies in four main areas; water use efficiency studies, farm management studies, economic surveys and advisory services such as demonstration farming, lectures, and farm management adjustment.

DEVELOPMENT OF THE SCHEMES

Most of the land preparation is carried out by the Ministry of Works using the border-dyke method. Figure 4.2 illustrates the rate of development of the three Mid-Canterbury and two South Canterbury schemes in operation before 1974. For each year the percentage of area prepared for border-dyking was calculated by dividing the total area prepared by the area of the scheme; these schemes were to be 60% irrigated (Fitzgerald, 1974). Table 4.2 provides a summary of the area border-dyked in each season, and also the total percentage of each scheme border-dyked by 1974. From both Table 4.2 and Figure 4.2 it is apparent that the schemes have not yet obtained the 60% irrigated figure after 20-30 years in operation. Valetta is the only scheme which is close to achieving this figure, and the reasons for this are discussed at length in Chapter Seven.

SUMMARY

A historical sequence of Government sponsored irrigation schemes in Canterbury since 1930 has been presented. By 1976 ten schemes were in operation, with one under construction and a further nine proposed. The development of the Winchmore Irrigation Research Station, established in 1946 by the Department of Agriculture, is discussed, as well as the rate of border-dyking on the schemes operational before 1974.

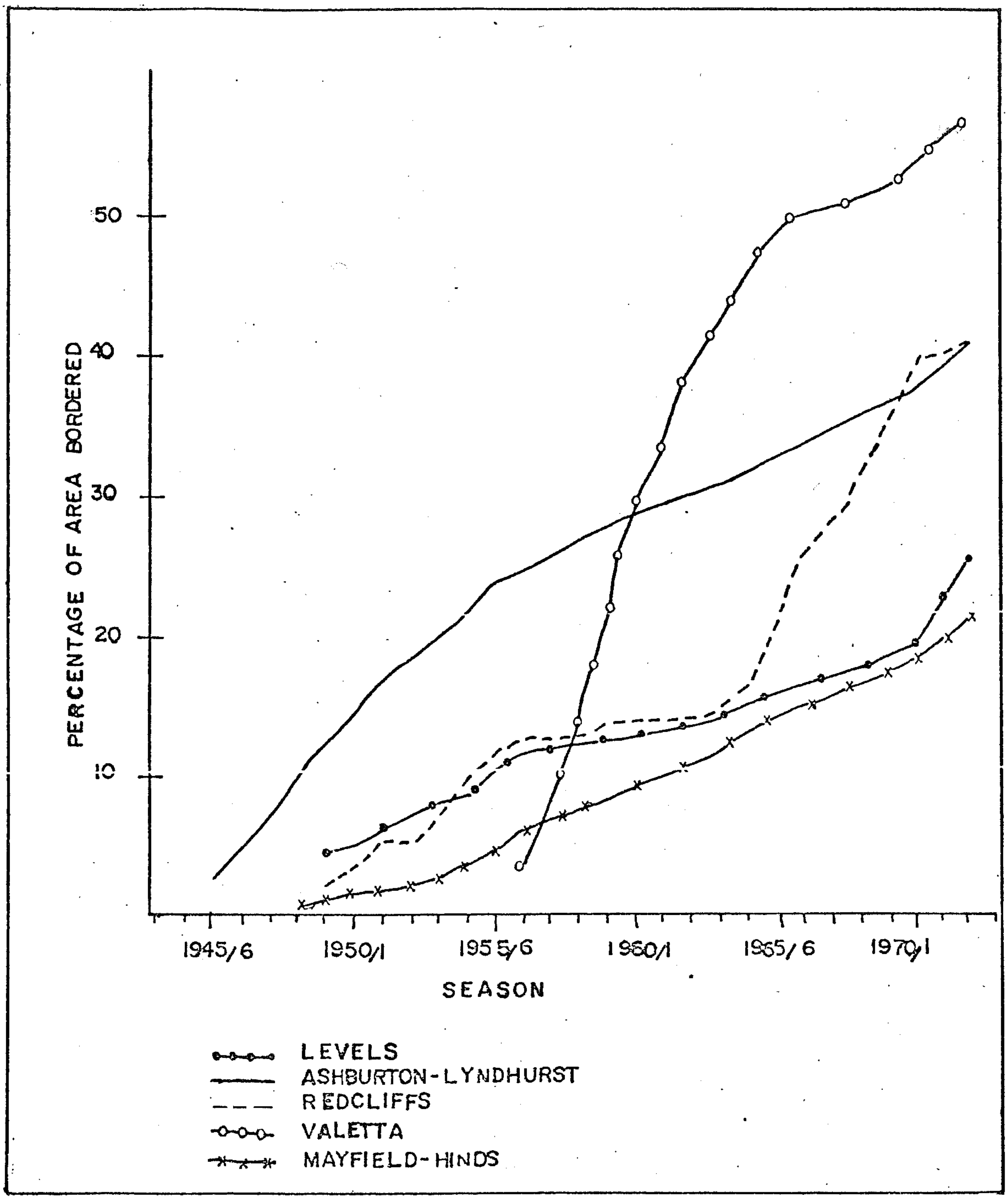


FIGURE 4.2: RATE OF DEVELOPMENT ON THE CANTERBURY IRRIGATION SCHEMES IN OPERATION BEFORE 1974

CHAPTER FIVE

THE CLIMATIC WATER BUDGET

BASIC CONSIDERATIONS

The Thornthwaite measure of potential evapotranspiration selected in Chapter One as the appropriate tool for this study belongs to the third W.M.O. (1975) group of methods used to study climates and their relation to vegetation and agriculture. The W.M.O. (1975) classification is

i) those methods which deal with the study of the influence of single climatic factors on the development of plant formation, cultivated species or varietal types. They have, for example, been applied by Koeppen (1923), Angot, Azzi (1954), Nuttonson (1959) and Schnell (1955) to study the relations between certain climatic factors and plant development and have also been used as a basis for climatic classification;

ii) those methods concerning the application of simple formulae in which values of the two main climatic elements; temperature and precipitation, are combined in a climatic index that may be used for studies of relations with plants or for climatic classification. These methods have, for example, been applied by de Martonne (1926), Emberger (1955), Gaussen (1963) and Watter (1960), to study climates or bioclimates in certain regions of the world, and

iii) those methods based on the concepts of energy and water balance, estimated by means of more complex formulae involving various climatic parameters such as temperature, day-length, humidity and solar radiation. Such methods have, for instance, been developed by Penman (1948), Prescott (1943), Thornthwaite (1958), and Turc (1961) to estimate the water balance for irrigation needs, and sometimes also to make general climatic studies. All methods use the same basic equation (W.M.O., 1975):

$$P - Q - U - E - W = 0$$

where: P is precipitation or irrigation water;

Q is runoff;

U is deep drainage passing beyond the root zone;

E is evapotranspiration;

W is the change in soil-water storage.

The models describing the water balance, vary mainly in the way in which they handle the evapotranspiration and soil-water storage terms.

The Thornthwaite potential evapotranspiration is used in this chapter to obtain a measure of drought severity during the growing season.

THE THORNTHWAITE METHOD

The Thornthwaite model of the climatic water budget (or water-balance), which may be used on a daily or long period basis, has been applied to the solution of numerous soil-water problems, including Mather's (1961) study of agricultural drought.

It is a comparison of the precipitation with the climatic demand for water measured by P.E. (potential evapotranspiration). Thornthwaite defined P.E. as the water loss from a large homogeneous, vegetation-covered area (albedo of .22 to.25) which never suffers from a lack of water. P.E. is thus a function of climatic conditions rather than the type of vegetation, type of soil, soil moisture content, or land management practices. Actual evapotranspiration on the other hand, depends on all of these factors.

According to the Thornthwaite model, whenever precipitation exceeds the climatic demand for water, the soil moisture storage will increase resulting possibly in a surplus of water and even runoff from the area. When the climatic demands for water or P.E. are greater than the precipitation, soil moisture storage will be depleted. By comparing the precipitation and the potential evapotranspiration for daily or monthly periods in a well-known and simple bookkeeping procedure, it is possible to obtain quantative values of:

a) the amount of water stored in the soil;

b) the water surplus or excess water above the climatic demands;

c) the surface water runoff; and

d) the water deficit or climatic demands for water not met by the available precipitation or stored soil moisture (Mather, 1973).

Before the calculations can be carried out, it is necessary to establish the depth of water that can be stored in the root zone of the soil when the soil is at field capacity. Soils differ in their water holding capacities, e.g. fine sands can hold approximately 100mm/m depth, sandy loams 150mm/m, silt loams 200mm/m and clays 300mm/m or more. The depth of rooting of plants varies not only from one species to another but also within the same species if grown on different soils. Thus the total amount of water that can be held in the root zone of a soil must be measured in each particular case or estimated from knowledge of the type of soil and type of vegetation growing on it. As it would be difficult to assess the water-holding capacity exactly for the whole of Canterbury an arbitrary moderate value of 150mm has been assumed for the entire study area.

Potential evapotranspiration (the climatic water demand) has been closely related to standard observations of air temperature by Thornthwaite (1948) through the expression

$$e = 1.6\ (10T/I)^{a}$$

where e = unadjusted P.E. in cm;

t = mean monthly temperature in ^{o}C;

I = annual heat index. This value is the sum of the 12 monthly heat indices i, where

$$i = (t/5)^{1.514}$$

$$a = 6.75 \times 10^{-7}\ I^{3} - 7.71 \times 10^{-5} I^{2} + 1.792 \times 10^{-2}\ I + 0.49239$$

T = Monthly temperature in ^{o}C

The value of e so determined is based on a 12-hour day and a 30-day month. Thus, it is necessary to adjust it by taking into account the actual number of hours in the day as well as the days in the month. The values of the correction factors vary with the latitude and month of the year, and can be obtained from tables provided by Thornthwaite and Mather (1957).

Mather (1971) provides a detailed explanation of the application of the model for the calculation of water balance components from monthly rainfall and temperature data. These calculations were programmed in FORTRAN II by Stone (1971) and this programme was rewritten in BASIC for the Wang 2200 T of the Geography Department, University of Canterbury.

Two examples of the computation are presented in Table 5.1.

a) YEAR = 1946

	J	F	M	A	M	J	J	A	S	O	N	D
P	32	38	35	31	108	86	34	50	103	90	77	80
PE	90	82	71	45	32	17	20	25	37	48	50	80
S	87	65	51	46	122	150	150	150	150	150	150	150
DS	-40	-22	-13	-4	76	27	0	0	0	0	0	31
AE	72	60	48	35	32	17	20	25	37	48	50	80
X	-17	-22	-22	-9	-0	40	13	24	65	41	26	-0

b) YEAR = 1971

	J	F	M	A	M	J	J	A	S	O	N	D
P	30	12	24	14	81	64	71	24	29	26	49	18
PE	105	92	81	51	40	25	19	28	42	59	73	102
S	44	26	18	14	55	94	146	142	130	104	89	51
DS	-28	-18	-8	-3	41	39	52	-3	-11	-25	-15	-38
AE	58	30	32	17	40	25	19	27	40	51	64	56
X	-47	-62	-49	-33	-0	-0	-0	-0	-1	-7	-9	-46

TABLE 5.1: TWO SAMPLE WATER BUDGET COMPUTATIONS USING LINCOLN DATA; a) A WET YEAR, and b) A DRY YEAR

(where P = precipitation, PE = potential evapotranspiration, S = Soil Moisture Storage, DS = Change in Storage, AE = Actual evapotranspiration, and X = Soil Water Budget).

THE RECORDS

The necessary monthly climatic data - rainfall and temperature - were obtained from eleven Canterbury climatological stations (Figure 5.1). These stations were chosen for two reasons. First, those with the longest records were selected. Christchurch, Lincoln and Waimate records extend back beyond 1900, and the other eight stations had readings beginning between 1900 and 1930. Table 5.2 provides a summary of record length. Second, their spatial distribution suggested they would be reasonably representative of conditions within the study area. There being two stations in North Canterbury (Hanmer and Balmoral), and in Mid-Canterbury (Christchurch and Lincoln), three in South Canterbury (Ashburton, Timaru and Waimate), and four along the Western Margins (Fairlie, Tekapo, Lake Coleridge and Mount Cook).

STATION	RAINFALL	TEMPERATURE
Hanmer	1905	1906
Balmoral	1921 (1905)	1928 (1880)
Christchurch	1894 (1880)	1864
Lincoln	1881 (1880)	1881 (1880)
Ashburton	1909 (1881)	1927 (1898)
Timaru	1897	1910 (1880)
Waimate	1898	1914 (1880)
Fairlie	1925 (1898)	1925 (1898)
Tekapo	1925	1927
Mt Cook	1930 (1925)	1910
Lake Coleridge	1913	1918 (1906)

TABLE 5.2: DATA RECORD LENGTH OF CLIMATOLOGICAL STATIONS

(Some records were extended back to parenthesised dates using longer neighbouring records).

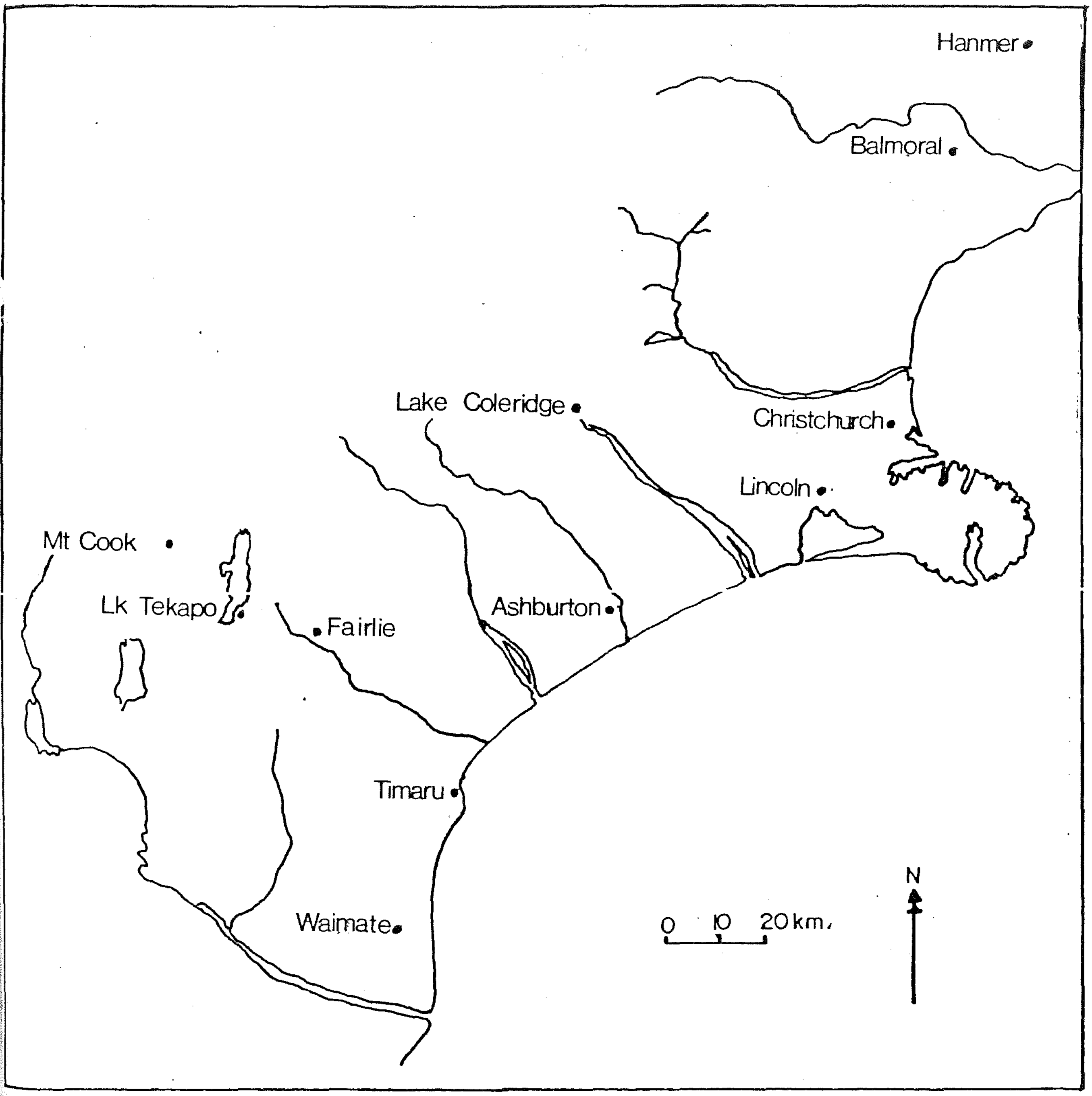


FIGURE 5.1: CANTERBURY CLIMATOLOGICAL STATIONS USED IN THIS STUDY

INTERPOLATED DATA

Before the monthly rainfall and temperature data could be used it was necessary to fill certain gaps in the data record. A complete monthly record is a pre-requisite for the water budget calculations. In order to do this a calibration programme was written for the Wang 2200T. This compared the available records of all stations for each month in turn, providing 12 product moment correlation coefficients and least squares linear regression equations for each pair of stations. This information was used in two ways:

a) to fill occasional gaps in the meteorological records; and

b) to extend records backwards.

The most accurate calibration equation for filling a particular gap was found by inspecting the correlation matrix of the appropriate month. For the sake of completing the record it was necessary in 262 cases to use this method to fill a gap. This represents only 1.6% of the total number of 16,240 data points. In one case it was necessary to use a relationship with an r value as low as .583, however, as shown in Table 5.3 the relationships were generally much stronger than this only thirteen r values used were below .7. Thus the overall impact on the accuracy of annual drought assessment was considered to be satisfactory.

Where correlations were high, 0.85 or greater, it seemed justified to extend the shorter data records backwards (see the parenthesised dates in Table 5.2). As Lincoln had one of the longest data records, and also correlated quite well with a number of stations (Table 5.3), it was used frequently in the interpolation procedure. Salinger (1978), however, notes that the exposure of the Lincoln raingauge was very poor during the period 1913-1935, mainly due to the poor siting and tree growth.

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
1	1	Tekapo	Lk Coleridge	.694
		Christchurch	Lincoln	.766
		Ashburton	Timaru	.810
			Lincoln	.646
		Timaru	Ashburton	.810
			Waimate	.807
		Fairlie	Tekapo	. 69
		Balmoral	Hanmer	. 85
	2	Tekapo	Lk Coleridge	.791
			Waimate	.851
		Mt Cook	Lk Coleridge	.724
		Christchurch	Lincoln	.909
		Ashburton	Lincoln	.806
			Timaru	.847
		Timaru	Waimate	.828
		Fairlie	Tekapo	.851
			Timaru	.807
			Waimate	.786
		Balmoral	Christchurch	.801
			Lincoln	. 78
			Hanmer	.848
	3	Tekapo	Lk Coleridge	.739
			Fairlie	.816
		Christchurch	Lincoln	.854
		Lincoln	Christchurch	.854
		Ashburton	Lincoln	.868
		Waimate	Fairlie	.829
		Balmoral	Lincoln	.737
			Hanmer	.869
	4	Tekapo	Lk Coleridge	.785
		Christchurch	Lincoln	.916
		Lincoln	Christchurch	.845
		Ashburton	Lincoln	.845
		Fairlie	Lk Coleridge	.767
			Timaru	.744
		Balmoral	Hanmer	. 84

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
1	5	Tekapo	Lk Coleridge	.724
		Christchurch	Lincoln	.931
		Ashburton	Hanmer	. 85
			Timaru	.843
			Christchurch	.821
		Timaru	Waimate	.868
		Fairlie	Timaru	.792
			Waimate	.768
		Balmoral	Hanmer	.911
	6	Tekapo	Lincoln	.762
			Fairlie	.768
		Christchurch	Lincoln	. 9
		Lincoln	Christchurch	. 9
		Ashburton	Christchurch	.818
			Lincoln	.785
		Fairlie	Timaru	. 89
		Balmoral	Hanmer	.845
	7	Tekapo	Lk Coleridge	.731
			Fairlie	.779
		Christchurch	Lincoln	.928
		Lincoln	Christchurch	.928
		Ashburton	Christchurch	.749
			Timaru	.829
		Fairlie	Timaru	.887
			Waimate	.809
		Hanmer	Ashburton	.778
		Balmoral	Ashburton	.735
			Hanmer	.813
	8	Tekapo	Lk Coleridge	.583
			Fairlie	.647
		Christchurch	Lincoln	. 89
		Lincoln	Christchurch	. 89
		Ashburton	Lincoln	.886
		Timaru	Waimate	. 89

TABLE 5.3: LIST OF CORRELATION COEFFICIENTS USED IN INTERPOLATION PROGRAMME

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
1	8	Fairlie	Ashburton	.699
			Timaru	.713
		Hanmer	Ashburton	.701
		Balmoral	Lincoln	.812
	9	Tekapo	Lk Coleridge	.787
		Mount Cook	Tekapo	.773
		Christchurch	Lincoln	.894
		Lincoln	Christchurch	.894
		Ashburton	Lincoln	.796
			Timaru	.919
		Timaru	Waimate	.931
		Fairlie	Ashburton	.806
			Timaru	.791
		Hanmer	Christchurch	.666
		Balmoral	Lincoln	.719
			Hanmer	.833
	10	Tekapo	Lk Coleridge	.811
		Mount Cook	Lk Coleridge	.743
		Christchurch	Lincoln	.928
		Lincoln	Christchurch	.928
		Ashburton	Lincoln	.869
		Timaru	Waimate	.867
		Fairlie	Timaru	.668
		Balmoral	Hanmer	.818
	11	Tekapo	Lk Coleridge	.842
		Christchurch	Lincoln	.902
		Lincoln	Christchurch	.902
		Ashburton	Lincoln	.832
			Timaru	.848
		Fairlie	Ashburton	.782
			Timaru	.697
			Hanmer	.753
		Balmoral	Hanmer	.838

TABLE 5.3: LIST OF CORRELATION COEFFICIENTS USED IN INTERPOLATION PROGRAMME

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
1	12	Tekapo	Lk Coleridge	.787
			Waimate	.715
		Christchurch	Lincoln	.898
		Lincoln	Christchurch	.898
		Ashburton	Timaru	.845
		Fairlie	Lk Coleridge	.882
			Ashburton	.815
		Balmoral	Hanmer	.851
2	1	Tekapo	Mount Cook	.861
			Ashburton	.836
		Mount Cook	Tekapo	.861
			Ashburton	.714
		Lk Coleridge	Christchurch	.815
			Balmoral	.901
		Ashburton	Christchurch	.942
		Timaru	Christchurch	.876
			Lincoln	.778
		Waimate	Christchurch	.965
			Lincoln	. 77
		Balmoral	Christchurch	.904
			Lincoln	.896
			Hanmer	.948
	2	Tekapo	Ashburton	.847
		Mount Cook	Tekapo	.879
		Lk Coleridge	Hanmer	.897
			Balmoral	.917
		Ashburton	Christchurch	.913
			Lincoln	.863
		Timaru	Christchurch	.829
			Lincoln	. 78
		Waimate	Christchurch	.893
			Lincoln	.801
		Balmoral	Christchurch	.905
			Lincoln	.898
			Hanmer	.965

TABLE 5.3: LIST OF CORRELATION COEFFICIENTS USED IN INTERPOLATION

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
2	3	Tekapo	Ashburton	.827
		Mount Cook	Lk Coleridge	.769
		Lk Coleridge	Lincoln	.872
		Ashburton	Lincoln	.855
		Timaru	Christchurch	.834
			Lincoln	.746
		Waimate	Christchurch	.891
			Lincoln	.773
		Balmoral	Lincoln	.899
	4	Tekapo	Christchurch	.853
		Lk Coleridge	Lincoln	.885
		Ashburton	Christchurch	.917
		Waimate	Timaru	.887
		Balmoral	Lincoln	.915
			Hanmer	.945
	5	Tekapo	Lk Coleridge	. 88
		Lk Coleridge	Lincoln	.832
			Balmoral	.898
		Ashburton	Christchurch	.888
		Timaru	Lincoln	.817
			Ashburton	.869
		Waimate	Timaru	.856
		Balmoral	Hanmer	.928
	6	Tekapo	Fairlie	.878
		Lk Coleridge	Lincoln	.852
		Ashburton	Christchurch	.883
		Timaru	Christchurch	. 82
			Ashburton	.884
		Waimate	Christchurch	.785
		Balmoral	Lincoln	.851
			Hanmer	.889
	7	Tekapo	Fairlie	.804
		Lk Coleridge	Lincoln	.866
			Hanmer	.879

TABLE 5.3: LIST OF CORRELATION COEFFICIENTS USED IN INTERPOLATION PROGRAMME

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
2	7	Ashburton	Christchurch	.847
			Timaru	. 88
		Timaru	Lincoln	.868
		Waimate	Timaru	. 86
		Balmoral	Lincoln	.826
			Hanmer	.892
	8	Tekapo	Hanmer	.796
		Lk Coleridge	Lincoln	.814
			Balmoral	.912
		Timaru	Christchurch	.784
			Waimate	.889
		Waimate	Christchurch	.833
			Ashburton	.901
			Timaru	.889
		Balmoral	Lincoln	.885
			Hanmer	.919
	9	Tekapo	Ashburton	.859
		Lk Coleridge	Lincoln	.828
		Ashburton	Christchurch	.916
			Lincoln	.828
		Timaru	Christchurch	.865
			Waimate	.893
		Waimate	Ashburton	.898
			Timaru	.893
		Balmoral	Lincoln	.907
	10	Lk Coleridge	Lincoln	.817
			Balmoral	.853
		Ashburton	Christchurch	.948
			Waimate	. 95
		Timaru	Christchurch	. 86
			Waimate	.907
		Waimate	Ashburton	. 95
			Timaru	.907
		Balmoral	Lincoln	.901
			Hanmer	. 95

TABLE 5.3: LIST OF CORRELATION COEFFICIENTS USED IN INTERPOLATED PROGRAMME

PARAMETER	MONTH	STATION	STATION CORRELATED WITH	CORRELATION COEFFICIENT
2	11	Lk Coleridge	Fairlie	.907
		Ashburton	Christchurch	.942
			Lincoln	. 87
		Timaru	Christchurch	.883
			Lincoln	. 82
		Waimate	Ashburton	.928
			Timaru	.921
		Balmoral	Lincoln	.881
			Hanmer	.947
	12	Tekapo	Lk Coleridge	.871
		Lk Coleridge	Balmoral	.927
		Ashburton	Christchurch	.959
			Lincoln	.909
		Timaru	Christchurch	.909
			Lincoln	.896
			Waimate	.918
		Waimate	Christchurch	.914
			Lincoln	.872
			Timaru	.918
		Balmoral	Lincoln	.893
			Ashburton	.927
			Hanmer	.911

TABLE 5.3: LIST OF CORRELATION COEFFICIENTS USED IN INTERPOLATED PROGRAMME

Comparisons with other stations indicate that this part of the record is suspect, and should probably not be used for analysis of climate change. Salinger (1978) recommends that the periods 1881 to 1912 and 1944 to 1975 are suitable for further analysis, but that 1936 to 1943 be used with caution. The temperature record prior to 1927 should also be used with caution in the analysis of climate change, because of various land use changes around the enclosure. However, it is unlikely that small changes in the mean values are significant in a study of this nature. Also, the records that were used for interpolation were mainly from the period 1881-1930, and thus the very suspect data was not used.

THE DATA ANALYSIS

The water budget provides a means of comparing the relative severity of annual agricultural droughts. The measure adopted in this work is the sum of all monthly deficits through a 12 month period.

Because the growing season of September-April needs to be considered in a single annual drought assessment, the 12 month period used for the summation of soil moisture deficits begins in July. As illustrated by the data in Table 5.1 deficits are very small outside the September-April period, so that the adopted annual measure is strongly weighted towards conditions in the critical period for irrigation.

In order to facilitate the comparison of relative severity a certain critical deficit has been recognised below which drought is said not to occur. This point lies between 115mm-125mm of deficit. This figure has been arrived at by a rather subjective method which involved relating recorded published wet and dry period data (Table 5.4) to the soil moisture deficit, and determining the approximate area of the soil water deficit where the transition of one to the other occurs.

YEARS	SWD (At Lincoln)	SOURCE
1859		Bondy (1950)
1875-77		Scotter (1972)
1889-91	287	
1897	271	Crowder (1973)
1907-08	248, 175	
1914	319	Rickard (1960)
1919	95	
1928	151	Rickard & Fitzgerald (1969)
1932	163	
1934-35	140, 198	
1947	57	
1958-59	99, 117	
1961	108	
1964	154	
1969-73	187, 145, 254, 178, 205,	

TABLE 5.4: PUBLISHED DROUGHT YEARS IN CANTERBURY

Of the above published drought analysis data 1919, 1947 and 1961 are the only drought years not recognised in terms of the soil water deficit (Figure 5.2). However, analysis of the soil water deficit reveals that drought conditions also occurred in 1921-26, 1949, 1953-54 and these are not mentioned in the published analyses. It is interesting to note, however, that The Press (Jan 7, 1950) described December 1949 as the driest in 16 years, and the whole year as being dry enough to severely affect crops (May 14, 1949). By December 1953 "semi-drought conditions prevailed" (The Press, Dec 16, 1953), and the entire summer was considered to be very dry (The Press, April 3, 1954).

The broad patterns revealed in the tables and graphs of this chapter will be described in the following discussion on Christchurch and Lincoln. As similar trends are exhibited by most of the stations the discussion of the records will, therefore, tend to concentrate on differences that occur from the trends exhibited by Christchurch and Lincoln.

CHRISTCHURCH AND LINCOLN

From Figure 5.2 it is evident that the climatic water budget in Central Canterbury is characterized by soil moisture deficits every year. The period 1880-1900, at Lincoln, was particularly dry, followed by a decade of greater variability in the deficits, with several dry periods, notably; 1903, 1906-8, and 1910. From 1910-1930, ignoring the suspect Lincoln data, a similar pattern was evident at Christchurch, with, however, the dry periods tending to be less severe. The similarity of the two stations is also apparent from Table 5.5, the average monthly soil water deficits. Apart from January and May the deficits tend to be slightly greater at Christchurch.

After 1936 it is evident that greater deficits were being experienced around Christchurch, rather than Lincoln as had formerly been evident. Salinger (1978) points out that this can be explained by the post 1936 Christchurch temperature. Temperature differences with other nearby stations reveal that the minimum temperature record

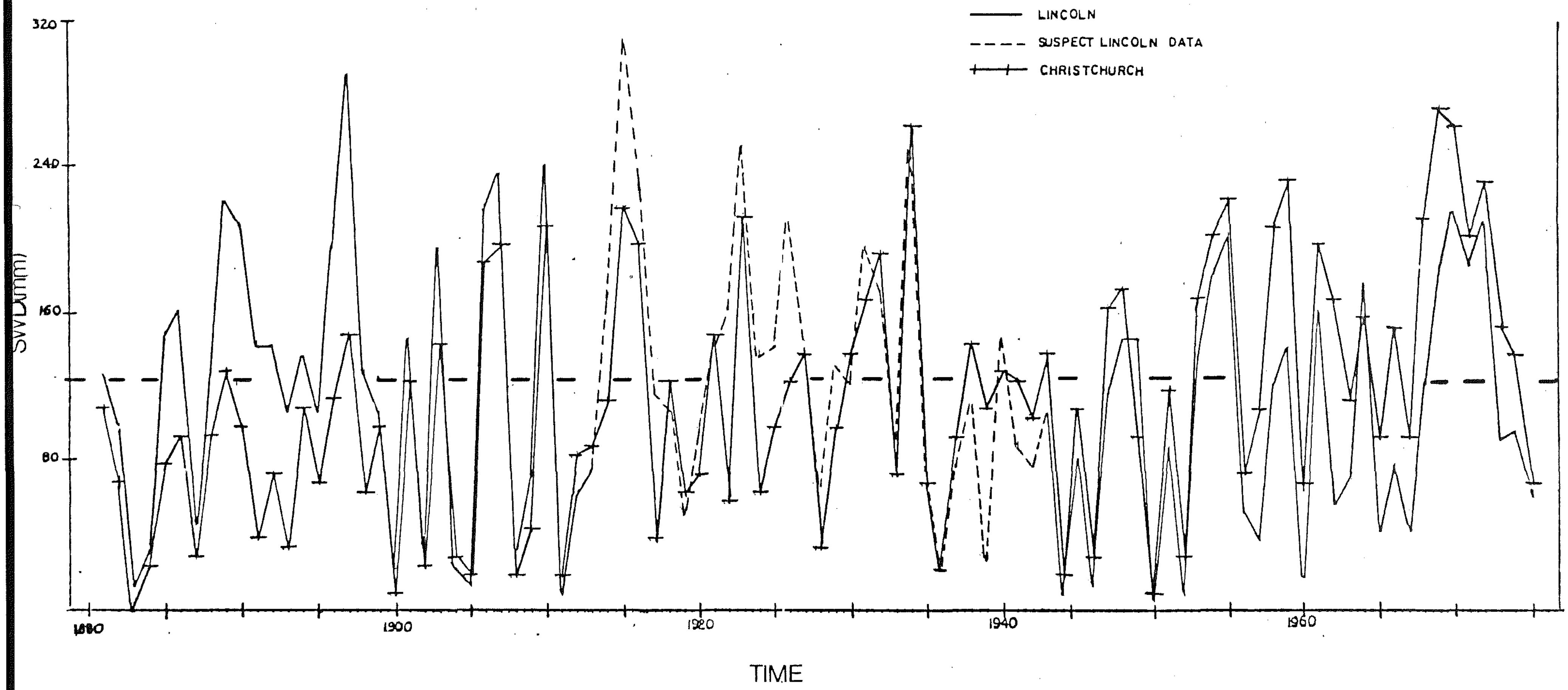


FIGURE 5.2: THE SOIL WATER DEFICIT IN CENTRAL CANTERBURY

is good from the point of view of climatic change analysis, but maximum temperatures show a warming in the period 1940 to 1975. Other Central Canterbury climatalogical stations (Lincoln, Ashburton, Winchmore and Eyrewell Forest) exhibit this phenomena but not to such a great extent (Salinger, 1978). Some of the warming in maximum temperatures, and possibly the alteration in the pattern of the calculated soil moisture deficit, may then be attributed to the urban growth of Christchurch.

From the late 1930s into the early 1950s the deficits are by no means as severe, and in 1944, 1946, 1950 and 1952 almost no deficits were recorded. After 1953, there is an increase in severity and in the extent of the deficits. Droughts were now lasting several years, culminating in the period 1968-1973 when severe deficits were recorded each year. This contrasts with the preceeding decades when droughts of greater than two years duration were uncommon.

	J	F	M	A	M	J	J	A	S	O	N	D
Hanmer	-17	-11	- 7	- 2	0	0	-1	0	-3	-2	- 3	-10
Balmoral	-28	-23	-22	- 8	-1	0	0	0	-3	-5	- 9	-20
Christchurch	-27	-25	-19	- 9	-1	0	0	0	-2	-2	- 9	-22
Lincoln	-29	-26	-18	-10	-1	0	0	0	-1	-2	- 6	-10
Ashburton	-20	-18	-12	- 6	-1	0	0	0	-2	-4	- 7	-14
Timaru	-27	-22	-17	-10	-3	-1	-1	-2	-4	-8	-11	-20
Waimate	-21	-19	-15	- 9	-2	-1	-1	-1	-4	-6	- 9	-16
Fairlie	-21	-11	-14	- 4	-2	0	0	0	-1	-6	- 6	-13
Tekapo	-28	-31	-21	- 9	-1	0	0	0	0	-4	-10	-20
Mount Cook	- 0	0	0	0	0	0	0	0	0	0	0	0
Lk Coleridge	-16	-18	-14	- 5	0	0	0	0	0	-2	- 4	-12

TABLE 5.5: MEAN MONTHLY SOIL WATER DEFICITS

NORTH CANTERBURY

Figure 5.3 summarizes the record of Hanmer and Balmoral - the two most northerly stations used in this study. From Table 5.5 it is evident that they both suffer less severe deficits than Central Canterbury. The severity of the deficit is considerably greater at Balmoral than Hanmer. Hanmer, situated in a mountain basin, receives considerably more rainfall, on average 1.5-2 times more than Balmoral. At the same time temperatures tend to be lower. Thus, it is natural to find lower deficits, and it can be seen that a number of years showed no deficit, and only two droughts were recorded in 1907 and 1917.

SOUTH CANTERBURY

The three most easterly stations in South Canterbury; Ashburton, Timaru and Waimate, have their soil water deficits depicted in Figure 5.4. It is evident that extremes of low and high deficits, for the most part occur in the same year at all three stations. In both Figure 5.4 and Table 5.3 Timaru records the highest deficits of the three. It is interesting to note, from Table 5.5, that Timaru and Waimate record average monthly deficits throughout the entire year, the only stations to do so.

THE WESTERN MARGINS

Mt Cook (Figure 5.5) suffers monthly deficits in only six years of the record; 1946, 1960, 1963, 1970, 1971 and 1972. Its mountainous location ensures a constantly higher rainfall and lower temperatures than the other stations.

Lake Coleridge and Tekapo (Table 5.5) are the only two stations to record February as the driest month.

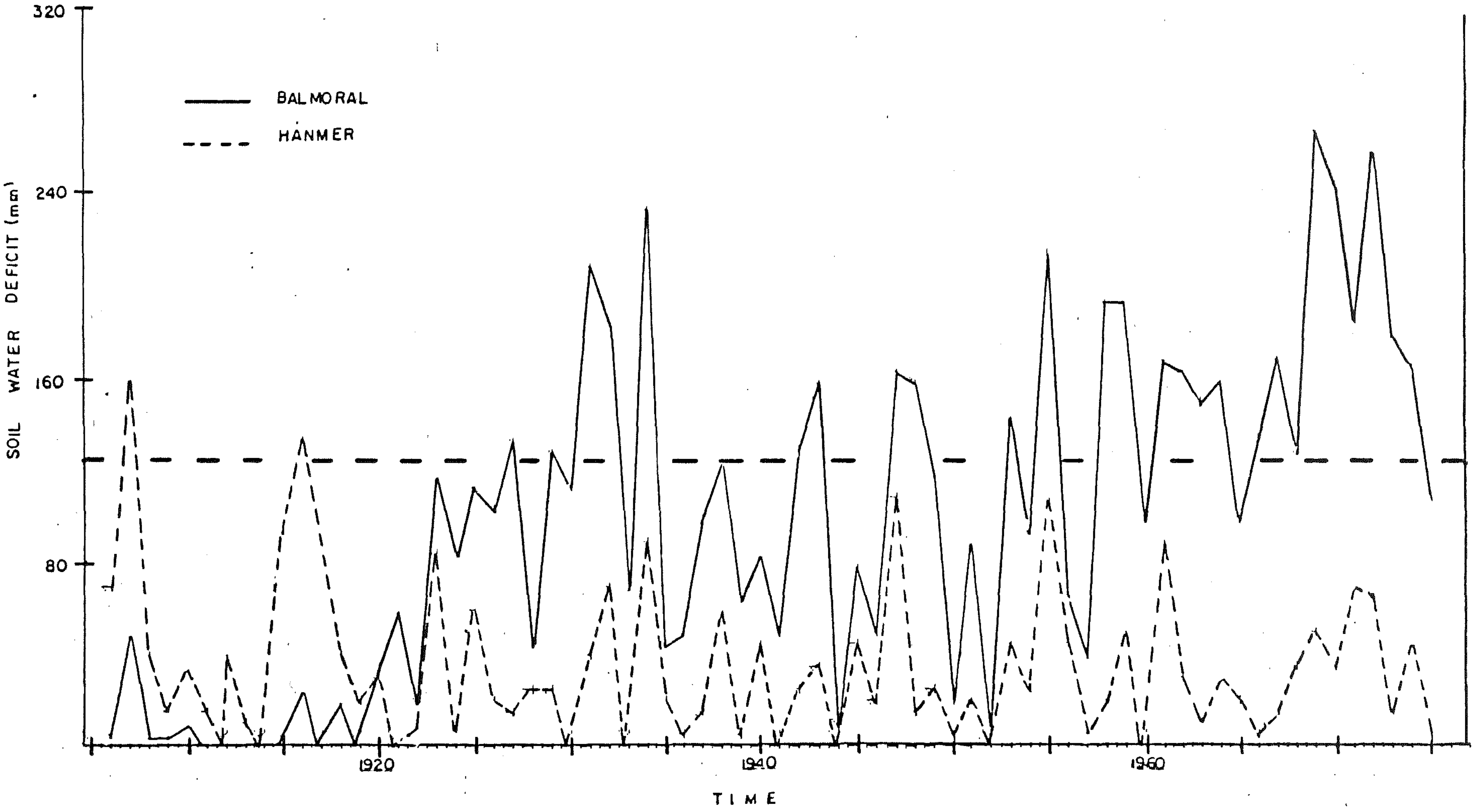


FIGURE 5.3: SEASONALLY ADJUSTED SOIL WATER DEFICITS OF HANMER AND BALMORAL

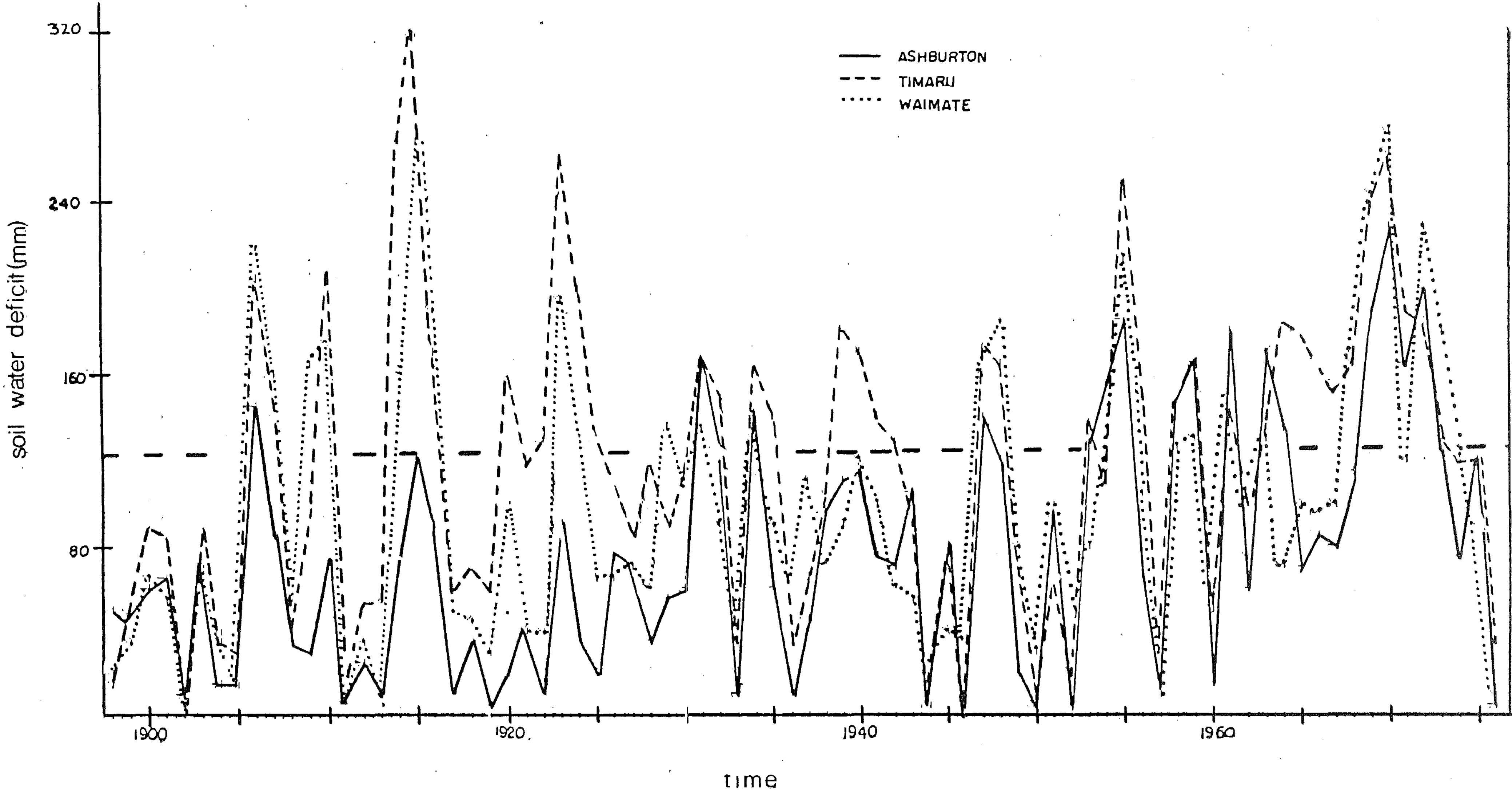


FIGURE 5.4: SOIL WATER DEFICITS (SEASONALLY ADJUSTED) FOR SOUTH CANTERBURY

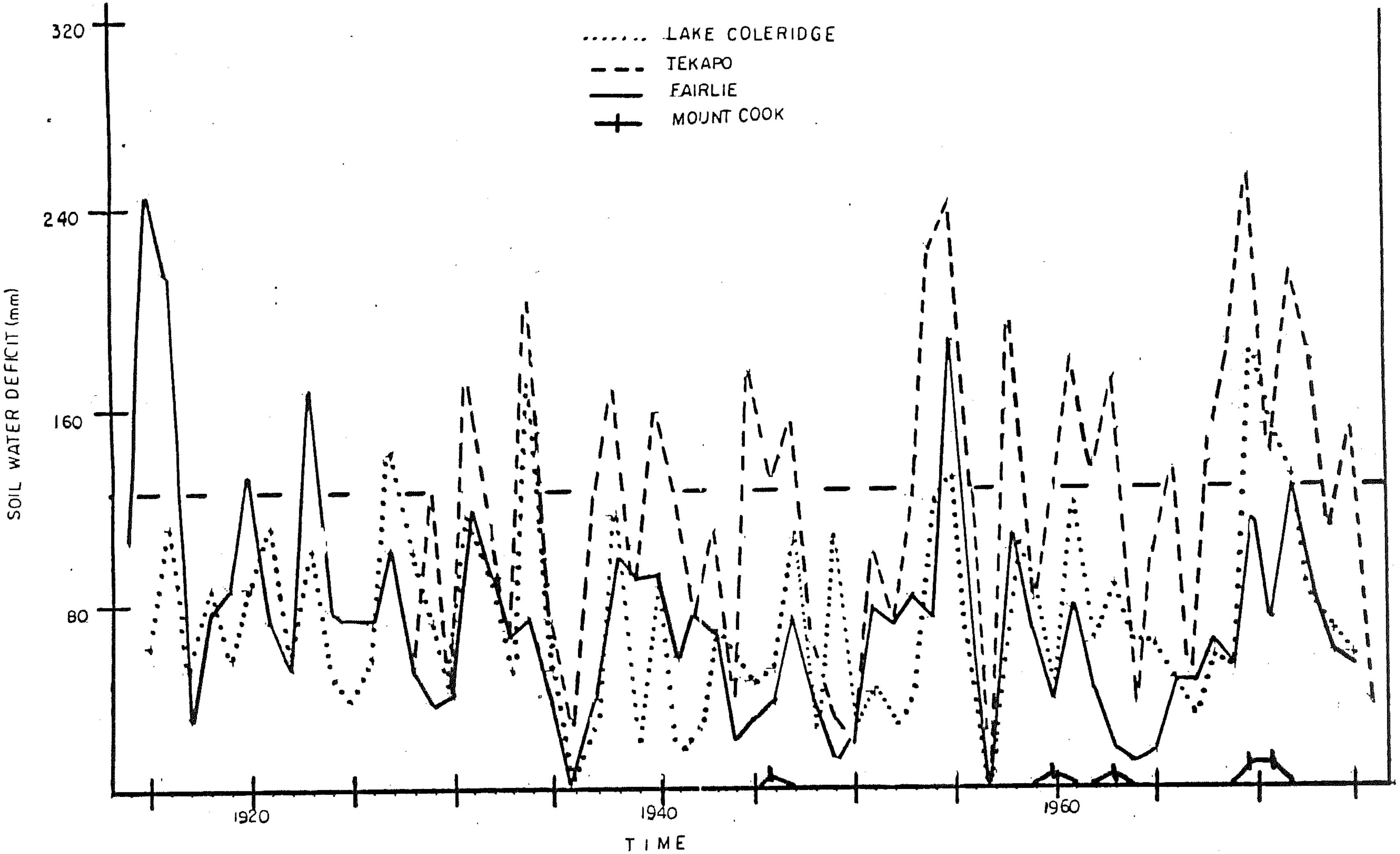


FIGURE 5.5: SEASONALLY ADJUSTED SOIL WATER DEFICITS FOR LAKE COLERIDGE, TEKAPO, FAIRLIE AND MOUNT COOK

The other stations are all driest in January. Both these stations experience a tendency in the 50s and 60s towards a smaller range of values, with deficits of fairly high magnitudes being more consistent, particularly 1958-1962 and 1968-1973 (Figure 5.5).

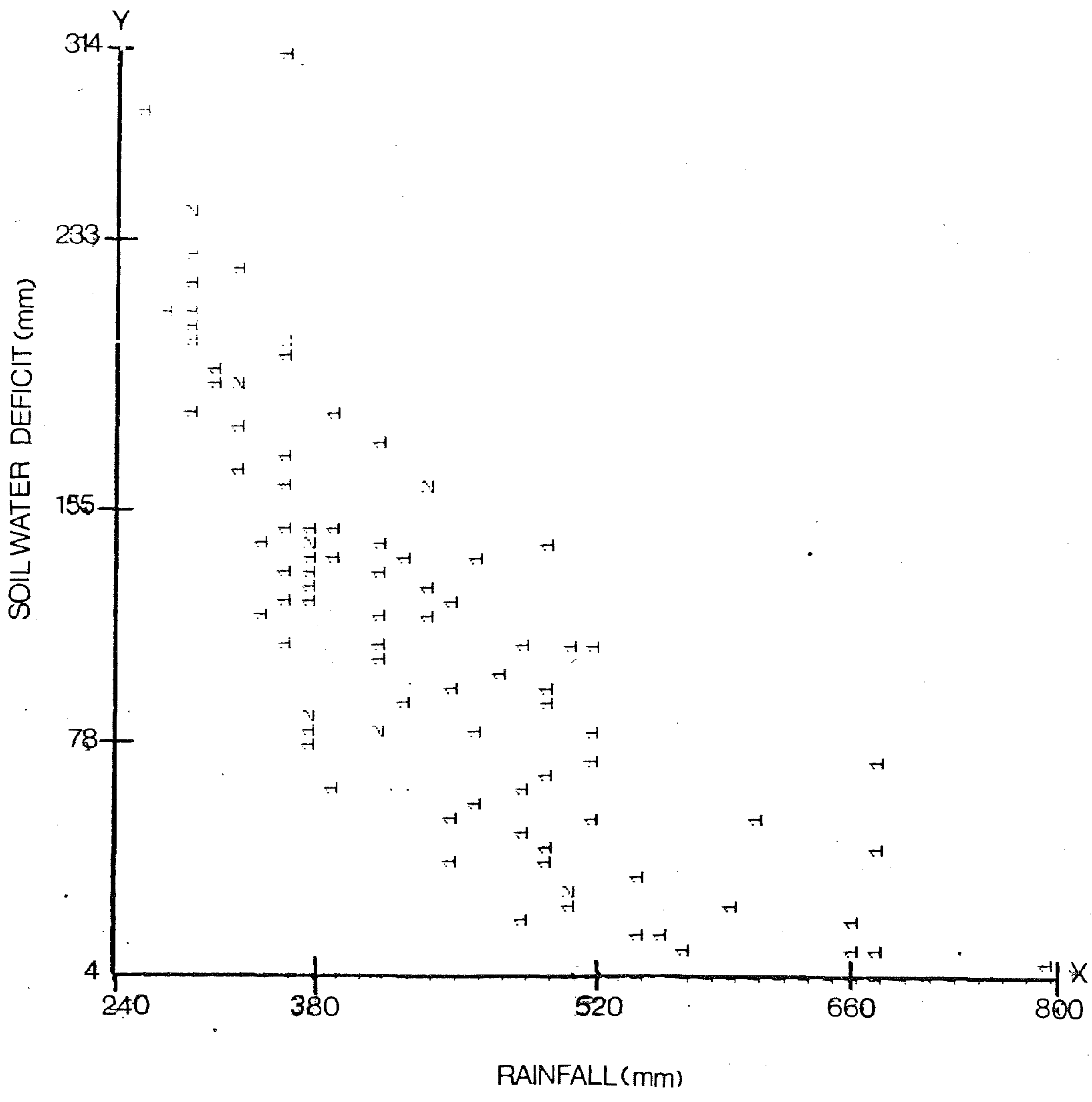
Apart from 1953, the deficits at Fairlie are not as great as those at the other stations (Figure 5.5), and between 1962 and 1967, there is a long period of consistently low values, not experienced by any other station except Mt Cook. The severe 1969-1973 drought was not felt either. The monthly figures (Table 5.5) reveal deficits lower than all the other stations except Mt Cook.

THE RELATIONSHIP BETWEEN RAINFALL AND SOIL WATER DEFICIT

Figure 5.6 provides a graphic representation of the relationship between summer rainfall (September-April) and seasonal soil water deficit (July-June) for Lincoln since 1881. A strong negative relationship yields a correlation coefficient of -0.79, which implies that rainfall figures account for at least 60% of the variance in soil water deficit. However, the scattergram reveals that the relationship is curvilinear which suggests that this percentage is an underestimate. A graph of Christchurch summer rainfall through time (Figure 5.7) was used to identify drought years. These were found to be similar to those previously identified with the soil water deficit.

Included in this graph is the pre-1880 summer rainfall figures for Christchurch. During this period there were at least three years, when a combination of high summer temperatures and low rainfall may have created severe agricultural stress; 1872, 1878 and 1880.

FIGURE 5.6: SCATTERGRAM OF ANNUAL (JULY-JUNE) SUM OF MONTHLY WATER DEFICITS AGAINST SEPTEMBER-APRIL RAINFALL.



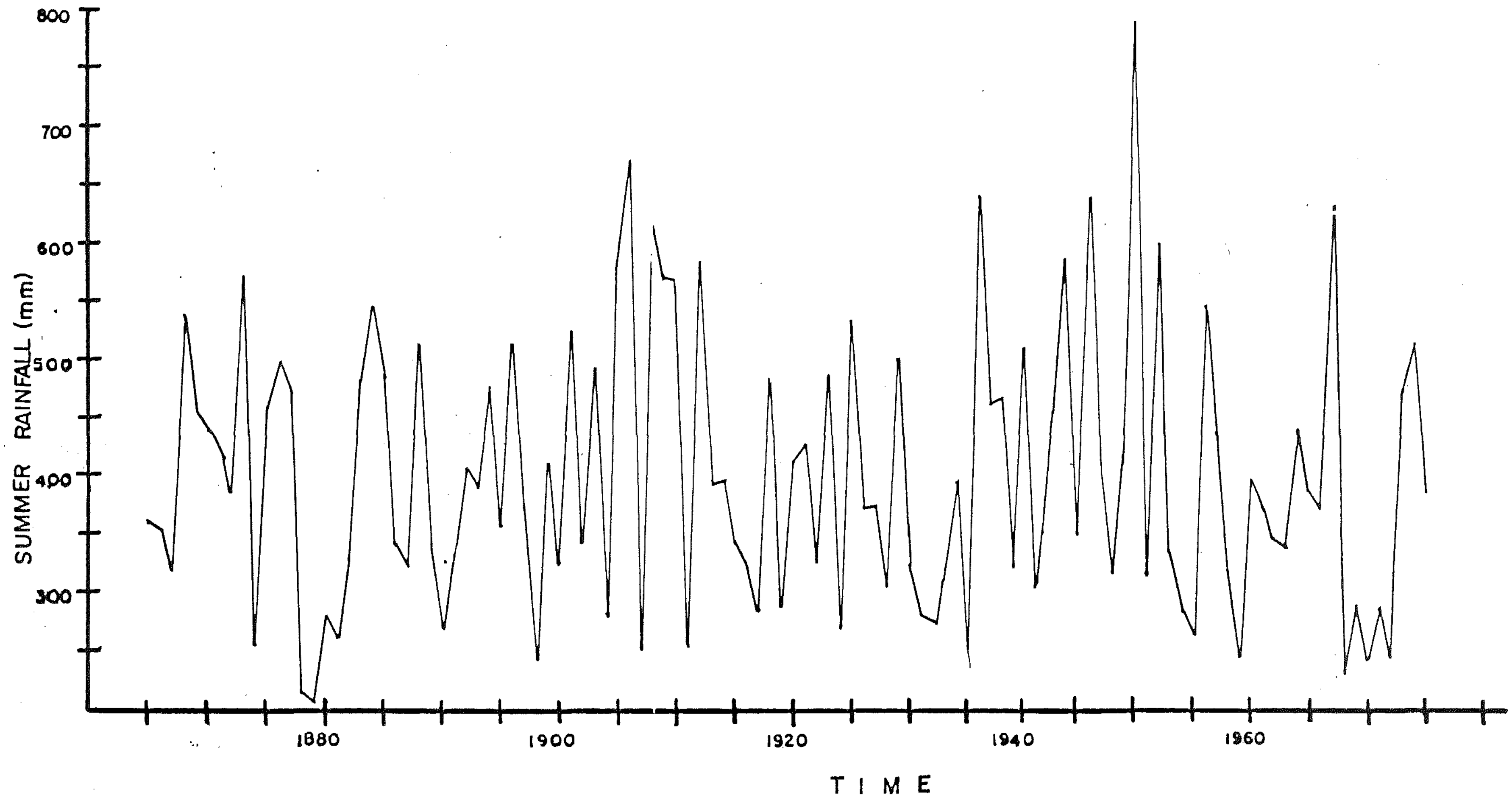


FIGURE 5.7: SUMMER RAINFALL (SEPTEMBER-APRIL) AT CHRISTCHURCH

SUMMARY

This study provided an analysis of soil water deficits throughout Canterbury over an extensive period. It is evident that soil water deficits are a common feature of the growing season in most of Canterbury. Apart from Mount Cook and Fairlie similar trends are manifested at all the other stations. The stations differ mainly in the severity of the deficit, Central Canterbury (Lincoln and Christchurch) suffering the most severe deficits.

This study has also identified the critical level of annual soil water deficit above which drought can be said to occur. This critical level of soil water deficit is approximately 120 millimetres.

An attempt was made to relate to agroclimatological studies, particularly with respect to irrigation, by the calculation of the soil water deficit. However, monthly and annual data is of limited value in agriculture studies, particularly in irrigation scheduling, for example, where day-to-day changes are important.

An analysis of summer rainfall suggests that the procedures used here may be unnecessary. Comparison of drought periods and their relative severity can be quite reasonably achieved through analysis of rainfall figures.

CHAPTER SIX

FACTORS INVOLVED IN THE DEVELOPMENT OF STOCK WATER RACES

INTRODUCTION

In Chapter Three a history of stock water race development in Canterbury was presented which outlined their construction dates, physical details and location. This chapter endeavours to explain the historical sequence of development by analysis of the following factors: personal experiences and political controls; economic and technological factors; and physical controls including climate.

The discussion will concentrate largely on the area between the Rangitata and the Rakaia Rivers, particularly the Ashburton County. In this area the climate, economic, political and physical factors all conspired to create a situation advantageous to the development of water races. To the south and in parts of North Canterbury the physical factor played a major role in hindering water race development on a large scale.

It has been demonstrated in Chapter Five that the impact of climatic stress was as great in South Canterbury as anywhere else in the Province. Yet the problems and conditions encountered there, ensured that the development of an artificial water supply would be limited. Chapter Two has shown that the physical terrain is largely unsuitable (Figure 2.2). Two particular problems were associated with this area; soil erosion in the downlands and flooding over the low country. As long ago as 1872 willows had taken possession of rivers and streams in some parts of the area and so seriously impeded the flow of water that the Orari Board of Conservators was appointed to exercise control and suggest remedies by which seasonal flooding might be overcome (Gillispie, 1958).

In April 1880, the conservators called a public meeting to discuss erosion and its prevention, but little was done except to cut willows which immediately began to grow again. The Orari and Opihi Rivers, and their tributary streams caused great damage when they overflowed, and much of the Geraldine-Temuka area suffered disastrously. Under such disadvantageous conditions it is little wonder water race development was so limited.

Even further north in times of flood, coastal farmers tended to hold the water races partly responsible. In 1890, however, argument between engineers and a farmer's legal action against the Selwyn County Council failed to prove that race water seeped into the Halswell River and raised its level.

In many areas north of the Selwyn County the perceived difficulty was not insufficient but rather superabundant water supplies. There the Counties Act had not been fully adopted so that the Oxford Road Board was responsible for the drainage of the swamp lands which lay in from and along the coastline. Until the 1880s, drainage was the all important question - until the drought of 1890-91, which is discussed later.

Using Figure 3.3, the period under discussion can be divided into four phases. These are shown in Figure 6.1. Although Figure 6.1 is a suitable description of the rate of water race development in all the areas discussed, the approximate dates of transition from one phase to the next vary according to the area under discussion.

The dates in Figure 6.1 relate to the Ashburton County. However, in the Selwyn County the third phase begins in 1871, and in 1890 for the Ashley County. These phases will be discussed in chronological sequence. This is convenient because each period of development tends to be dominated by a distinctive set of factors.

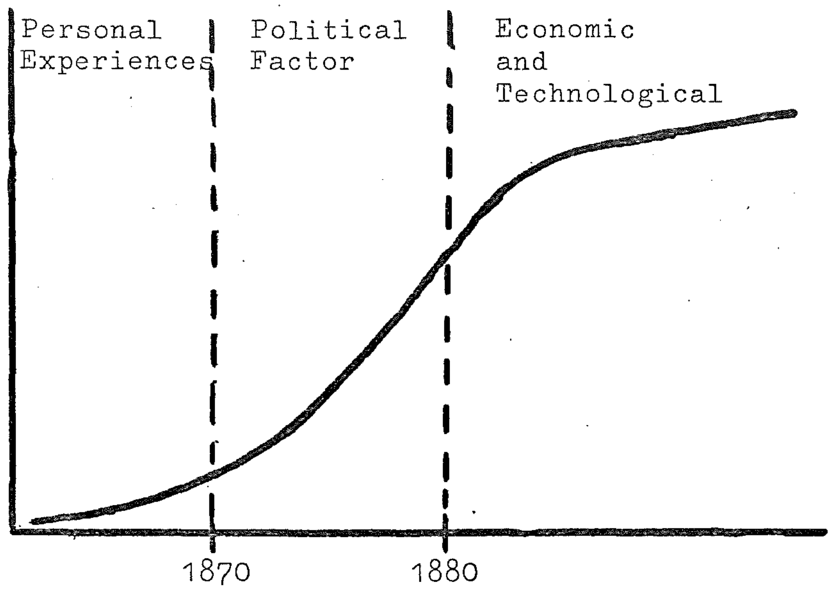


FIGURE 6.1: THE PHASES OF WATER RACE DEVELOPMENT

BEFORE STOCK WATER RACES

Throughout the first decade of settlement on the plains, particularly between the Rangitata and Rakaia Rivers, the supply of water for domestic and stock purposes was a very real problem. Wells tapping ground water, tanks filled by rain water or carting from streams were the chief sources. However, other factors prevented water race development until the 1860s. First, the major problem facing the settler was the conversion of the tussock lands into pastoral runs. This was achieved by fire and the plough. Second, Australian-bred Merino flocks were run on most of the stations, and the Merino wethers seemed to do quite well without water provided they were undisturbed (Foster, pers. comm.).

During this early period (prior to 1860) wool, for which the price was fairly stable, was the most important production. Mutton production increased slowly but the market was limited, and in the early years the sale of sheep to the newcomers was the chief source of income for several of the large runholders (Leadley, 1952).

By the early 1860s, these sales fell off as most runs were stocked and able to produce their own replacements. At the same time wool prices began to fluctuate. The runholders were faced with two alternative methods of maintaining their income, either to continue livestock farming on a more intensive scale or else to turn to arable farming. The gold discoveries in Otago and Westland and the Maori Wars in the North Island provided markets for both wheat and meat. However, the chief handicap to the intensification of livestock farming was the lack of water for stock. There were still vast acreages of the fans which had no access to water, and on these areas carrying capacity was severely restricted.

THE WATER RACE IDEA

Although there was little irrigation in Britain from whence most of the settlers came, irrigation had been experimented with in Australia and it was quite logical that similar methods should be tried in the water deficient areas of the Canterbury Plains.

With the discovery of gold in Otago came a large influx of Californian miners, many by way of the Victorian diggings. They brought with them many of the techniques which had been used in California and Victoria, and the use of open channels for conveying water was one of these. Parcell (1951) points out that by mid-1863, the year of the first recorded water race construction in Canterbury, water and water races were the most important subjects affecting the Otago mining industry.

There is no definite evidence, however, that the construction of open races for agriculture had any direct relationship to the races of the Otago miners.

Charles Reed, of Westerfield, had come to New Zealand by way of Victoria, where he had presumably had some experience of farming under dry conditions. Prompted by his desire to work the run along the lines of the English estates, but hampered by the lack of water and, no doubt, by the dry conditions, between 1867-1869 (Figure 5.2), he began work in 1869 on his races which were to influence other runholders to construct similar improvements.

Colonel Brett, who was the prime mover in the construction of water races between the Rakaia and the Waimakariri Rivers, and who had served in the Indian Army, applied his knowledge of irrigation practices in India to the problem which he encountered on the Canterbury Plains (The Press, Dec. 24, 1977). However, it was not until the early 1870s that his scheme was mooted and by that time there was already a substantial length of races in the Ashburton area.

THE POLITICAL FACTOR

It was in 1871 that Colonel Brett persuaded the Provincial Council to engage C.E. Fooks to report on the possibility of 'irrigating' the Malvern district. It is possible that Colonel Brett's urgings were precipitated by the dry conditions of 1867-70 (Figure 5.2).

The controversy raised by the report published in 1872, over the use of channels and pipes was resolved in the following year, and the two revisions of the report were completed by 1874. Also in 1874 the Canterbury Water Supply Act was passed, which empowered the Superintendent of Canterbury to construct out of moneys apportioned for the purpose in 1872, water works in the district between the Waimakariri and Rakaia Rivers (Chapple and Graham, 1965). Yet construction did not begin until August 1876, possibly prompted by drought conditions in 1875.

According to Scotter (1972) these same drought conditions between 1875-77 (Figure 5.2) encouraged ratepayers to meet at Rakaia in January 1878 and to petition the Ashburton County Council to undertake an 'irrigation' scheme immediately. It has already been demonstrated in Chapter Three that 'conditions appeared to favour prompt action'. Yet three years passed before water flowed into the first county stock race.

A number of factors were responsible for the delay. The drought ended. The extreme economic conditions, especially the depression of this period, did not dispose the councillors to plan calmly for the future. They took a further year to appoint an engineer, William Baxter, in February 1879. By June of that year, the council was studying a water supply bill clause by clause. It then referred the bill to the road boards for comment and considered the objections that were raised. Two acts were necessary. A counter petition was presented to Parliament, probably representing a last flicker of road board resentment at having to surrende any rating powers. Consequently, the clause giving the council the power to rate and raise loans was struck from the initial bill and another had to be passed (Scotter, 1972).

On his side, Baxter could not be accused of lack of speed. He reported on the scheme two months after his appointment, fixing on Pudding Hill Stream as the site for the first intake (Figure 3.2). But in spite of the success of open channels re recommended the use of glazed earthenware pipes six inches in diameter. There followed an eighteen month period of discussion between Councillors over the relative merits of open and closed channels.

The farmers themselves immediately recognised the advantages which the races brought, and within three months of the opening of the Pudding Hill intake deputations were received by the Council from other areas. These deputations and the further extension of the scheme have been discussed in Chapter Three.

Other counties became interested in times of drought. A drought occurred in 1882, and was followed in 1883 by Amuri asking for a report by Baxter. In the same year a Geraldine Council proposal of a loan for the construction of stock races was turned down by the ratepayers (Scotter, 1965). A reduced scheme was, however, set going in the following year.

According to Scotter (1965) some parts of the Ashley County, particularly in the Eyre region west of Swannanoa, suffered as much from lack of water at times as did Selwyn or Ashburton. During the eighties a solution to the problem could be sought only at the road board level; early in the decade the Oxford Board extended from the Eyre River some private water races which it had taken over; later the Rangiora Board received an estimate of $24,000 for head-works and channel to deliver 53,472,000 litres a day (Canterbury Times, 21 Jan. 1887; 11 Feb. 1887). The farmers were more concerned at the price of wheat than at any deficiency in production, until the drought of 1890-91. Then East Eyreton ratepayers brought pressure to bear and in 1892 a Waimakariri-Ashley Water Supply Board was set up. The Board decided on a $62,000 scheme to take water from the Waimakariri at Rockford. Two wet seasons and the opposition of Marmaduke Dixon finished that project. Dixon and his son had already cut a channel through the bank of the Waimakariri River near their Eyrewell property. As a result of successful experimentation, Dixon opposed the Water Board's plan and offering instead to cut a channel from Brown's Rock, some 4 km from the upper Waimakariri bridge, to the Warren estate where it could connect with the Oxford Board's supply. After two years of deadlock and quarrelling the scheme described in Chapter Three was constructed.

The small Action scheme was an exception to the rule that at this time the Council could not obtain support for irrigation. According to Scotter (1972) the depression was entering its last, and in many ways its worst years, and there had been much controversy over aspects of water supply, especially on the southern plains and at Wakanui.

During the drought of 1898, economic conditions were beginning to improve, and the Ashburton County Council had secured favourable terms on a large loan for schemes on the Rangitata Plains and Dorie. However, the succeeding moist systems (Figure 5.4) and some small difficulties killed interest.

THE TECHNOLOGICAL FACTOR

The rapid expansion of the Ashburton County network during the 1880s, graphed in Figure 3.3, occurred during a period of market extension, and was accompanied by technological improvements in transport, refrigeration and farm machinery.

The first shipment of frozen mutton reached London in 1882, and refrigeration seems to be a basic factor in the development of the county, since so many of the changes which occurred were part of the transition to the fattening of stock for the freezing trade. But the county could not have availed itself of the opportunities for progress which refrigeration brought if it had not been for the stock water races. The races came at a time when an answer to the water supply problem was required, and also at a time when refrigeration became practicable.

THE COMPLETION OF THE ASHBURTON COUNTY NETWORK

The final phase in the development of water races is again exemplified with the Ashburton network. The nineties were a period of slower development as far as the water race network was concerned (Figure 3.3). The existing schemes were extended as the network of races became closer and closer, and the remaining private races were taken over - part of the Springfield system being the last to be transferred, in 1895 (Leadley, 1952) - but no new intakes were built. However, this does not mean that the whole county was now satisfied as far as stock water supply was concerned. During the nineties there were several years in which severe deficiency was still clearly evident (Figure 5.5), particularly in the Acton, Dorie, Coldstream, and Ruapuna districts.

The Ruapuna farmers in 1899, prompted by the drought of the previous year, guaranteed payment on a loan of $14,000 - the only action of this kind taken in the county. It was unfortunate therefore that the project proved more awkward and expensive than others. For the first time, the Rangitata was to be tapped. An intake was to be built at the gorge and the water used for irrigation as well as for stock water races. Shingle slides and floods were responsible for considerable damage to the headworks during the constructional stages. The work dragged on much longer than was intended and was further impeded by wintry conditions which earned for the intake the permanent title of "Klondyke".

Modifications in the original plans were required, greater lengths of concrete were introduced to carry the water across the shingly terraces, and the whole idea of irrigation from this intake was abandoned. The Klondyke headworks were officially opened in March 1900, but it was not until nearly three years later that sufficient protective works were constructed for the scheme to operate satisfactorily.

In 1909, following the 1907-8 drought (Figure 5.5) the council took over the works on the Acton run, the intake was enlarged, and a further 20 km of main race were constructed.

The Ashburton-Rakaia plains were now well supplied - the branching channels from these various intakes gave an adequate coverage to the whole interfluvial area. But the southern part of the county was still inadequately supplied, particularly the Carew-Ealing-Coldstream area. Another supply from the Rangitata was deemed necessary and in this case construction was not hindered by floods or other accidents. The intake, opened in 1915, was built at Cracroft, the original main race was 20 km long and was planned to serve over 350 km of subsidiary channels.

SUMMARY

It is clear that the initiative for stock water races originated in Ashburton. Once the problems associated with land occupation had been overcome, farmers there were able to consider alternative methods of water supply. At first the innovation of water races was slow (Figure 3.3), and the water race experiments were treated with considerable scepticism. Once the idea caught on, particularly with the impetus given by Council involvement, the system expanded rapidly. Expansion was particularly rapid during 1880s when refrigeration and new land laws gave incentive to further subdivision of land and intensification of farming. During the 1890s and into the first two decades of the twentieth century development slowed, as the system began to provide an adequate coverage of the Ashburton Plains.

Climatic stress played a twofold role in the development of water races. In the first instance, the climatic environment was water deficient, and it was obvious that efficient agricultural practice would require more water. However, until the end of the first phase when there were higher priorities, nothing was attempted. During succeeding development phases other factors wielded greater influence. However, one can see that at times of climatic stress increased interest in water race development was evident. For instance; the 1875-77 drought prompted a petition to the Ashburton County Council in 1878, the 1882 drought was followed by interest expressed in Amuri and Geraldine Counties in 1883, during the 1890-91 drought East Eyreton ratepayers agitated for a water supply board, and Ruapuna farmers in 1899 following the previous year's drought also gave support to a scheme in their area.

By 1910 substantial schemes were operating in North Canterbury and also Mid-Canterbury. South Canterbury, due to the nature of the physical conditions other than climate, was the only large tract in which very little development had occurred. Thus, between the Rangitata and Rakaia Rivers there was not only the incentive provided by the average climatic stress and frequent droughts, but also advantageous conditions of soil and terrain; a land of far-sighted enthusiasts, who were not only farmers but often held positions of responsibility in County Councils as well. Finally, economic conditions and technological advances encouraged agricultural intensification and the development and extension of stock water races.

The dominance of a particular set of factors during the different phases of development make it difficult to isolate a particular factor as being the most important.

CHAPTER SEVEN

CLIMATE AND IRRIGATION

INTRODUCTION

A number of factors, including socio-economic, political and technological factors, have been significant in determining the spatial and historical development of government irrigation schemes in Canterbury. The first section of this chapter will look at each of these factors in turn and describe their historical occurrence and influence on the present situation.

The second half of this chapter concentrates solely upon the effect of climate on the development of irrigation. Several lines of evidence are statistically analysed in order to determine the influence of climate. The validity of the results and the problems encountered in attempting to analyse the influence of climate are also discussed.

GOVERNMENT RECOGNITION OF THE VALUE OF IRRIGATION

Recognition of the value of irrigation was first manifested at the local government level in the late 1880s. Drought conditions at the beginning of 1886, together with urging for years from various newspapers, at length persuaded the Ashburton County Council to consider a trial irrigation scheme. In March 1887, the council responded to requests from farmer's meetings and chose a reserve at Elgin to serve as an experimental irrigation farm.

Scotter (1972) comments that it is curious that the test was so abruptly terminated in August, 1890. However, a contemporary writer reported that the ratepayers ....

> "have seen one of the worst bits of land in the district, the County Council farm at Elgin, transformed being barren save for weeds; into land yielding crops of every description."
>
> (Guardian, 3 August, 1889)

Thus, it would appear that the farm had achieved its purpose and demonstrated the results that could be obtained from irrigation, and its continuation was probably unnecessary.

National government involvement in irrigation development did not begin until the 1930s when economic circumstances and social considerations rendered it politically useful. A number of authors, including Evans (1977) have discussed in detail the influence of these factors in the government decision so they shall only be briefly mentioned here.

The government's decision to seriously consider irrigation of the plains at this time was partly the desire to increase production and with it population, and partly the desire to provide employment for the large number of unemployed. As a result of drought conditions in 1930 the D.S.I.R. field supervisor advocated irrigation in Ashburton County (The Press, 6 Sept 1930). Along with the urgings of interested bodies, the results of several small private experiments with irrigation in Mid-Canterbury, as well as an irrigation farm at Seafield, convinced the government of the benefits which would result from irrigation.

In 1935 construction began on three large government schemes at Redcliff, Levels Plain and Ashburton-Lyndhurst. The first two schemes, opened in 1936 and 1937 respectively, were not well supported at first. For example, in its first year of operation only five farmers availed themselves of the Levels scheme. Two factors account for this. In an article in the Press (9/6/30) the D.S.I.R.

field supervisor commented that, 'South Canterbury farmers look upon irrigation farming and slave-labour as being one and the same thing'. Moreover, as revealed in Figure 5.3 several wetter years followed the opening. Thus climatic conditions and the prevailing attitude of farmers ensured that the schemes were not used extensively until 1939 which was considerably drier than the previous years.

The construction of the Ashburton-Lyndhurst Scheme and the Rangitata Diversion Race, was completed in 1944, three years later than originally estimated due to the interruption of World War II. According to Scotter (1972) it aroused little enthusiasm. Farmers objected to the destruction of 'tangible assets' for a 'problematical benefit', and considerable controversy was aroused on the effect of seepage from the diversion race.

In November 1948 water became available on the Mayfield-Hinds scheme (The Press, Jan 15, 1949) originally it had been intended that this scheme should have its own intake on the Rangitata River. As The Press (Jan 21, 1950) reports, 'a few years ago work on the scheme halted because all labour and materials were required for hydroelectric power development'. However, a 'temporary' link was made into the diversion race, and is still in operation.

DELAYS IN IMPLEMENTATION

During the late forties and early fifties officers of the M.O.W., who were responsible for the schemes, believed that the steadily increasing use being made of the schemes (Table 4.2) indicated that farmers having seen irrigation in operation were showing growing confidence in it (The Press, Jan 21, 1950).

However, the support was by no means general as a newspaper article the following year revealed.

> "From the inception of the scheme there had been a strong body of opinion against it. This opposition to a very large extent could be traced to an objection to change in the established routine of farming ... Immediately the project was opened there was a tendency for farmers to irrigate small portions of their farms only to provide an insurance against loss in abnormally dry years, and perhaps slightly increase their carrying capacity ... A further defect of the supply on demand system was that irrigators would defer demanding water as long as possible in the hope that a weather change might save the trouble and expense of irrigation. The result was that when water was required everyone wanted it at once, which made the physical operation of the scheme difficult, and moreover expensive."
>
> (The Press, Jan. 20, 1951)

Agitation from farmers outside the schemes, however, was encouraged by the Canterbury Progress League. Of particular interest was the proposed scheme for the area between the Rakaia and the Waimakariri Rivers. Irrigation committees were set up in the various counties. Several meetings of farmers interested in irrigation were held in the area in May and June 1950. There was a meeting of farmers north of the Waimakariri River at Swannanoa, where a committee was set up in order to obtain signatures in support of establishing a scheme (Minutes of The Canterbury Progress League, Sept 1950). By 1952, however, the Progress League wrote to the Minister of Works asking him to inspect the area of the proposed scheme,

> "A scheme was all that the League asked for in the meantime, because it was realised that the scheme was unlikely to be carried out for several years."
>
> (Minutes of the Canterbury Progress League, March, 1952)

Indeed, even now, several decades later the scheme is still only in the planning stage (The Press, May 26, 1978).

In February, 1965 farmers in the Glenavy-Morven area requested an investigation of the irrigation potential of the district. A pilot farm was established to investigate land preparation problems and to demonstrate irrigation, and construction of the scheme began in 1974. It is not unreasonable to expect delays in the implementation of large schemes as considerable planning is involved. However, it was not until March, 1969 that the Minister of Works authorised preparation of a firm proposal and estimates for the scheme (Fitzgerald, 1970). During 1966 interest was expressed by local bodies in the Central Plains area in investigating the potential for irrigation. The Malvern County Council offered the Ministry of Works two cusecs to irrigate an experimental demonstration farm. In May 1967 the Ministry of Works informed the Malvern County Council that at the present time funds were not available for developing a demonstration farm (Fitzgerald, 1970). However, it is also true that while funds were not available, neither were there any plans in the M.O.W. priorities for the Rakaia area at that time (S. Hamblett, pers. comm.).

THE EFFECT OF IMPROVED DRYLAND FARMING TECHNIQUES

In the late 1940s and early 1950s the rapid development of irrigation might have been expected. The Canterbury Progress League was encouraging farmer interest. Several schemes were operating successfully. Everything was ready to proceed with the implementation of irrigation. However, postwar economic and social conditions were quite different to those operating when the schemes were originally envisaged and implemented.

At this time the shortage of electricity meant that engineers and labour were required to construct power stations and few could be spared for irrigation work (The Press, Jan 21, 1950). Postwar food shortages and the increased demand for wool had raised prices for farm products. In addition important developments in dryland farming technology which had begun before the war were greatly expanded. Therefore, buoyant prices and increasing levels of dryland farming technology greatly reduced the comparative advantages of irrigation.

Evans (1977) details the improvements in dryland farming techniques. The essential reason for the rapid post-war development was that all the practices included in advanced dryland farming technology fulfilled the criteria for fast adoption rates outlined by Lionberger (1960):

a) low capital input

b) familiar work routines

c) absence of new skills

d) practice able to be adopted gradually.

Where irrigation had been adopted, it was largely within Government resettlement schemes. Approximately one-third of the farmers in the irrigated zone in the 1950s were young ex-servicemen settled by the Lands and Survey Department on Crown Land. By 1953 25 former servicemen were established on irrigated farms in the Winchmore area and another nine in the Mayfield-Hinds area (The Press, Feb 14, 1953). In January 1955 the Lands and Survey Department announced that they were to develop 3,240 hectares in the Valetta-Tinwald area for irrigation and eventual settlement (Fitzgerald, 1970). Construction started in 1956 and water became available in 1958. Each of the farms purchased and developed by the Lands and Survey Department had approximately 40% of its area prepared for border-dyke irrigation (The Press, Feb 14, 1953).

The unusual degree of preparation by the government explains the relatively steep curve in Figure 4.3 for Valetta-Tinwald during the 1950s.

RENEWED DEVELOPMENT DURING THE 1970s

In Chapter Four several public meetings were described which occurred in 1969. As well as Oxford and Loburn, the 1969-73 drought appears to have caused a renewal of support for irrigation in several other areas of the Province. In November 1969 a meeting of 90 farmers at Darfield formed a committee to ascertain support for irrigation in 64,750 hectares south of the Waimakariri. In January 1970 the Minister of Works instructed the Commissioner of Works to give full consideration to the interests of the Waimakariri-Ashley irrigation committee.

In 1974 construction began at Morven-Glenavy, and the development of the Waiau Plains. Recently it was announced that three out of the four blocks on the Waiau Plains irrigation scheme are expected to receive water a year earlier than expected (The Press, August 25, 1978). A spokesman for the M.O.W. commented that factors in the advancing of the dates for water availability were the good liaison that had been established with local farmers and their committee, and also the standardization of structures.

Notwithstanding the good liaison between the farmers and the committee, and the dry conditions in late 1977 - early 1978, there is strong opposition to the scheme. An article in The Press (Sept 1, 1978) highlights the strong reservations of some farmers on the Waiau Plains. One concern is that the sort of farming that is being promoted may not necessarily be viable, and that those who do not want to irrigate feel pressured to do so. It is also suggested that irrigation would accelerate and accentuate seepage problems in areas within the scheme. In reply the District Commissioner of Works, Mr P.F. Reynolds commented:

> "this was no doubt the first major irrigation scheme in North Canterbury and a certain amount of apprehension about it could be understood, but problems likely to occur had been overcome apparently quite satisfactorily on six other major irrigation schemes between the Rakaia and Waitaki Rivers.... With co-operation and a will to make something work all problems could be overcome."
>
> (The Press, Sept 1, 1978)

THE EFFECT OF CLIMATE

It is difficult to determine the precise role played by climate as a trigger in the development of government irrigation schemes. Table 7.1 shows the years of droughts indentified in Chapter Five along with the years in which construction commenced on the schemes and the years in which various pressure groups were established. Because of the small number of committees and schemes a rigorous analysis of the data is not easy.

Although a majority of the committees were established within one year after a drought it is also true that a majority of drought years were not associated with the establishment of committees. The number of years in which droughts did or did not occur are summarized in the following contingency table. It should be noted that Committees formed within one year of a drought have been classified as occurring in a drought year and that the formation of more than one committee in a particular year has been given no extra weighting. Unfortunately a null hypothesis, stating that there is no relationship between the classifying criteria, cannot be tested with Chi-square because of the low expectation of committee formation.

DROUGHT YEARS	ESTABLISHMENT OF COMMITTEES ETC	BEGINNING OF CONSTRUCTION
1928-29	1931. Committee consisting of the Canterbury Progress League and Canterbury Chamber of Commerce.	
1932-33	1933. Committee consisting of the Ashburton County Council, local bodies and departmental representatives.	
1934-35		1935. Redcliff Levels Plain Ashburton-Lyndhurst
		1937. Mayfield-Hinds
1947-48		
1948-50	1950. Committees in Malvern County and Swannanoa.	
1953-54	1955. Ballot in Rakaia district.	
		1956. Valetta
1958-59		
1961-62		
1964-65	1965. Request for survey from Slenavy-Morven farmers.	
	1966. Ashburton-Hinds Irrigation Association Request for experimental farm in Malvern County.	
1969-73	1969. Committees formed at Oxford, Loburn, Darfield, Waimakariri-Ashley.	
		1973. Greenstreet North Rakaia
		1974. Morven-Glenavy

TABLE 7.1: DATES OF DROUGHTS, EXPRESSION OF INTEREST AND CONSTRUCTION SINCE 1930

		YEARS OF		TOTAL
		DROUGHT	NON DROUGHT	
YEARS IN WHICH	COMMITTEES FORMED	5	2	7
	COMMITTEES NOT FORMED	14	26	40
	TOTAL	19	28	47

TABLE 7.2: CONTINGENCY TABLE - SUMMARISING THE FORMATION OR NON FORMATION OF COMMITTEES DURING PERIODS OF DROUGHT OR NON DROUGHT

The schemes themselves are even fewer in number. But in any case a meaningful statistical relationship between climate and commencement of construction is not likely in view of the lengthy periods of planning which may precede construction. Neither is it easy to identify the role of climate in initiating the schemes. The triggering for the early schemes was clearly related to political decisions taken during the particular economic climate of the 1930s, and factors other than climate certainly influenced the resettlement of returned servicemen in the 1950s. While it is tempting to speculate on the association of the 1969-73 drought with the recent renewed interest in irrigation development it must be noted that approval for the Morven-Glenavy scheme was given in 1968 before the onset of the drought. However, the continued expansion after 1974 may to some extent be related to the drought.

In view of these difficulties it was decided to explore two other avenues in an attempt to evaluate the influence of climate over irrigation development. It was hoped to make a general assessment of the changing attitudes of the farming community to irrigation from the character of newspaper articles;

and to examine the responses of farmers within government schemes, for whom irrigation might represent a practical solution to the drought hazard, from available data on areas border-dyked. Because of the relative lack of irrigation in the 1930s and 40s, along with the complications of depression and World War during this period the studies were confined to the last three decades.

The original intention of the newspaper analysis was to examine changes through time in the character of newspaper articles concerned with irrigation. A sampling procedure was devised which entailed the perusal of the weekly agricultural section of "The Press", identifying those articles concerned in some way with irrigation, and then classifying them into one of six categories; examples outside Canterbury, opposition, results, construction, support and policy/cost/problems. The results of the classification are summarized in Figure 7.1.

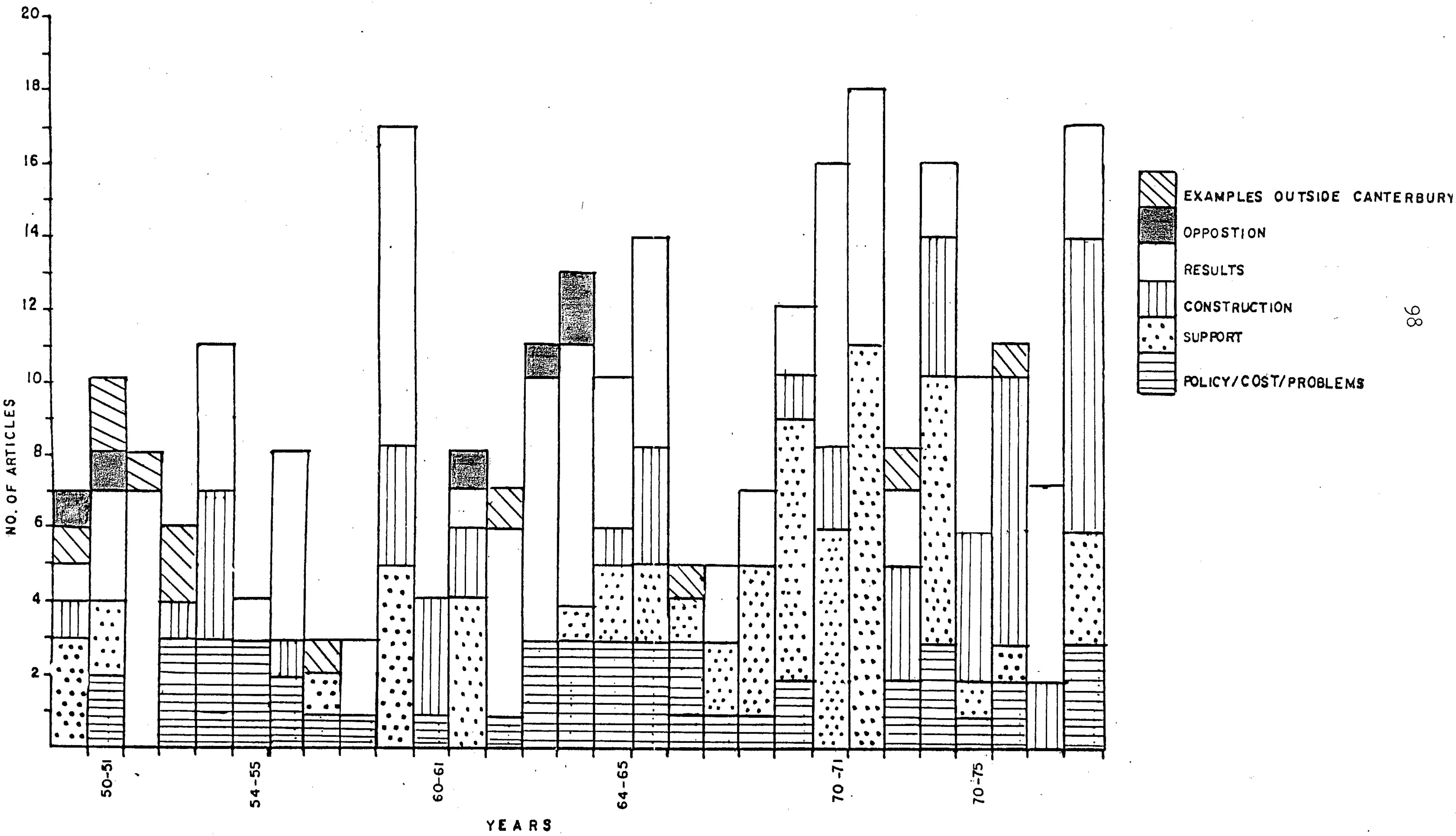
A difficulty with the sampling procedure arose in trying to classify the articles. Each article appears in only one category, but numerous articles discussed several aspects of irrigation, therefore at times articles were placed in one category rather than another, usually based on the general theme, or the topic of the majority of the article.

During the preceding chapters of this study quite a large amount of opposition to irrigation has been detailed. Thus, it is surprising to note that the opposition category is the smallest, with only six articles against irrigation being published over the 29 year period. This illustrates a factor which became apparent throughout the data collection period, namely, that the opponents to irrigation are usually less organised and less vocal than the proponents. The proponents, particularly in the 1950s and early 1960s, were well championed by the Canterbury Progress League who were able to gain much publicity, as their meetings and activities were generally attended by journalists.

Because of the small number of articles in the opposition category it was not possible to examine satisfactorily the relative strength of opposition and support as a response to drought intensity. Instead a crude analysis of the total number of articles concerned with irrigation was undertaken. Definite fluctuations in the number and type of articles published are apparent in Figure 7.1. Superficially, at least, the increase in the number of articles would seem to relate to periods of climatic stress. When the relationship was statistically tested using a simple linear regression of the number of articles in each season on the corresponding soil water deficit a product moment correlation coefficient of 0.37 resulted. This value, which is significant at the 5% level for 28 degrees of freedom, would appear to indicate that the number of articles appearing in any one particular season is weakly influenced by climatic conditions.

Unfortunately the changing character of the newspaper through the study period makes difficult any interpretation of the absolute numbers of articles on irrigation. For example, over this 29 year period growth in the size of both the paper and the weekly agricultural section is evident. From one page in the 1950s, to two pages in the 1960s, the agricultural section has grown to its usual three pages. This makes it difficult to determine whether the large number of articles in the 1970s is a response to increased irrigation, or merely a function of increased space available for articles, or a combination of both. Thus the correlation may be spurious, for the growth in farming pages parallels a slight tendency for increased soil water deficits through the study period.

FIGURE 7.1: NEWSPAPER ARTICLES ON IRRIGATION PUBLISHED IN THE FARMING SECTION OF "THE PRESS", 1949-1978



(A regression of annual soil water deficits for the Canterbury stations was associated with correlation coefficients of between 0.5 and 0.6). If real, the weakness of the relationship may be explained to a certain extent by an increased likelihood of irrigation articles appearing during periods of irrigation development for these periods will not coincide with droughts. This suggestion is upheld by studying the changing nature of the categories over time. During the late 1950s and particularly since 1973 the number of articles appearing on the subject of construction increased, both being periods of construction (Table 7.1).

The use of water in Canterbury irrigation schemes in relation to climate has been investigated by Fitzgerald (1974). In this study the influence of climate on the decision to invest in irrigation has been examined by studying farmer response in terms of the area border-dyked on the five schemes constructed before 1974. The data used are derived from figures tabled by Fitzgerald (1974) describing the total area border-dyked within each scheme at the end of each financial year. These cumulative values were used in the construction of Figure 4.2. The information required for this study, the area prepared for border-dyking each year, was obtained by simple subtraction and is shown in Table 4.2.

Correlation of these areas with the annual soil water deficit showed conflicting results between schemes. It can be seen from Table 7.2 that only three schemes yielded significant correlation coefficients; Mayfield-Hinds, Levels and Redcliff - all within the range 0.39 to 0.47. A number of factors may account for this apparently weak relationship.

On each scheme the farmers are canvassed during the winter by the Ministry of Works and Development to determine the amount of border-dyke preparation required.

	ASHBURTON-LYNDHURST (N=30)	MAYFIELD-HINDS (N=25)	VALETTA (N=18)	LEVELS (N=25)	REDCLIFF (N=26)
Annual Soil Water Deficit/Area 0 - lag	-0.24	0.39	-0.24	0.42	0.47
Annual Soil Water Deficit/Area 1 Year lag	-0.09	0.54	-0.1	0.53	0.19
Area/Time	0.56	0.62	-0.87	0.45	0.28

TABLE 7.3: CORRELATION COEFFICIENTS FROM THE CORRELATION OF ANNUAL SOIL WATER DEFICIT AGAINST THE AREA BORDER-DYKED, AND THE AREA BORDER-DYKED AGAINST TIME

(_ significant at the 5% level

= significant at the 1% level)

This work is generally completed within the following year. Thus, the response to a climatic extreme in terms of the area border-dyked may well be a year out of phase. Therefore, the regressed areas on soil water deficits were lagged by one year. Although the percentage variance explained by annual soil water deficits almost doubled for Mayfield-Hinds, the improvement was not quite as good for Levels, and no other significent correlation occurred. In particular the small Redcliff scheme which showed a significant correlation for unlagged data showed correlation at all with lagged data.

Table 7.4 shows that the areas commanded by some schemes increased markedly through the study period. This gives an increased opportunity for irrigation development which is independent of climate. However, because climatic stress also shows a tendency to increase (as discussed in the previous study) these two influences cannot be separated. Both may influence the positive correlation coefficients for the border-dyked area against time recorded in Table 7.3.

YEAR	ASHBURTON-LYNDHURST	MAYFIELD-HINDS	VALETTA	LEVELS	REDCLIFF
1945	1376			4856	1862
1950	1376	2914		4856	1862
1955	2590	14569		5180	1862
1960	2590	34400	7042	5180	2185
1965	2590	34400	7042	5180	2185
1970	2590	34400	7042	5180	2185

TABLE 7.4: THE AREA COMMANDED (HECTARES) BY THE SCHEMES

In the case of Valetta there was a strong tendency for the area border-dyked to decrease through time, and this may be related to the filling up of the scheme. There was a strong negative correlation coefficient of -0.87 recorded between the area border-dyked and time. In order to remove the effect posed by this decrease in available area, the residuals from the regression on time were themselves regressed against climate. This resulted in an extremely high correlation coefficient of 0.78. Thus 60% of the variance in area border-dyked at Valetta can be explained by climate.

It must not be forgotten that the measure of annual soil water stress adopted to assess drought stress in this study is not a truly accurate measure of the climatic stress experienced by the farmers. However, it is considered that most of the variance in the border-dyked data remains unexplained because of economic and other unexplored factors.

SUMMARY

In the 1930s the combination of climatic conditions and the availability of land suitable for irrigation in Ashburton County convinced the government that large-scale irrigation development would provide the means to achieve certain social and political aims.

Despite efforts by the authorities to promote the rapid development of irrigation after the completion of the early schemes, farmers appeared reluctant to have their land prepared for it. This attitude has prevailed up to the present day. This can be explained in terms of Lionberger's (1960) discussion, the opposition and slow on farm development would appear to result from irrigation not meeting the requirements outlined earlier for successful innovation.

In the 1950s support for irrigation was fostered by the Canterbury Progress League. However, the advances in dryland farming technology meant that there was less incentive for farmers to adopt irrigation. Where it was adopted, it was largely due to government resettlement schemes i.e. Valetta. This trend continued into the 1960s. Where interest was expressed e.g. by Irrigation Committees it did not coincide with governmental ability or willingness to undertake any development. For example, in the early 1950s hydro power development had a greater priority, and in 1964 the Rakaia area was included in the development priorities. Thus, areas north of the Waimakariri River have had to wait until the 1970s for irrigation development as the priorities were previously concentrated south of the Rakaia.

Eyeball analysis of the relationship between drought periods and interest in the development of irrigation suggests that it is greatest during drought periods or immediately following.

However, the scanty data precludes meaningful analysis. Statistical analysis of the interest expressed through correlation of the number of newspaper articles against the annual soil water deficit produced a very weak trend, which may result from difficulties encountered in the sampling procedure.

Although the initial results of correlation of the area border-dyked against the annual soil water deficit were conflicting, significant trends were revealed in four of the five schemes constructed before 1974; Valetta, Mayfield-Hinds, Redcliffs and Levels. The unexplained variance is probably due to the economic factor and other unexplored factors.

CHAPTER EIGHT

EVALUATION AND CONCLUSIONS

INTRODUCTION

This study has attempted to evaluate the influence of climate on the development of agricultural water supply systems in Canterbury since the 1850s. Two types of agricultural water supply system have been studied; stock water races, and government sponsored irrigation schemes. The stock water races have been studied from their early beginnings up to 1930, and the government sponsored irrigation schemes have been studied from 1930 up to the present day. The influence of climate has been studied, along with other relevant factors, by assessing the impact of annual soil water deficits upon the development of water supplies.

This study has provided a synthesis of two themes; the history of water supply development and the estimation and occurrence of agricultural drought in Canterbury. The most complete account of the development of agricultural water supplies to date has also been provided. Previous authors have confined their attention to either one particular aspect of the development or else to developments in one particular area of Canterbury. For instance, Fitzgerald (1970) is mainly concerned, with the historical development since the inception of the government schemes, while Paul (1945) is concerned solely with stock water race development. Leadley (1952), Scotter (1972), and Evans (1977) all confine their attentions to Ashburton County.

Although this study has been biased towards developments in

Ashburton County a discussion of the other areas of Canterbury has been provided. The predominance of Ashburton County throughout this study has resulted for several reasons. First, there is a large amount of readily obtainable primary and secondary resource material discussing developments in Ashburton County, and not in other areas. Second, Ashburton County contains the origins of early stock water race development, and a large amount of development occurred there. The final reason is that until 1974 three of the five government irrigation schemes in operation were in the Ashburton County.

PHYSICAL BACKGROUND

The discussion in Chapter One revealed that irrigation development is one of the options available to ameliorate the hazard climatic stress poses upon agricultural systems. However, certain physical conditions need to be met if the development of irrigation is to be viable. Physiographic factors, particularly the surface relief, make large areas of the downlands and foothills unsuitable for present large-scale irrigation. This has meant that the study has been confined to the Canterbury Plains where extensive areas of flat land provide suitable physiographic conditions for irrigation development. Certain soils are also better suited for irrigation development. Free draining sandy loams and silt loams are the soils most suited for irrigation. The occurrence of soil types and their suitability for irrigation on the Canterbury Plains has been summarized in Figure 2.2. It is worth noting that the development of irrigation in a particular area is as much a function of the ease of physical development as it is a function of climatic stress

The climate of Canterbury has been studied, with particular reference to the problem of soil moisture faced by the agriculturalist, by the use of Thornthwaite's estimation of potential evapotranspiration. Using the concept of potential evapotranspiration the monthly soil water deficit was calculated for eleven Canterbury climatological stations. The deficits occur mainly in the period September-April, with surpluses usually being recorded in the winter months.

The annual soil water deficit was used as a measure of drought intensity. A critical level of 120mm of annual soil water deficit was recognised above which drought occurs. This was achieved by relating the pattern of the July-June sum of soil water deficit to the periods of "generally recognised drought". A good correlation between the two was apparent.

The study of the spatial patterns of annual soil water deficit revealed that annual deficits are a common feature in nearly all of Canterbury. The Mount Cook region was the only study area where virtually no annual deficits were recorded. Then annual deficits were shown to be most severe at Christchurch and Lincoln. Similar patterns were evident at Balmoral, Ashburton, Waimate, Tekapo and Timaru although the severity of the annual deficits was not as great. Fairlie and Hanmer recorded few annual deficits above the critical level of 120mm suggesting that the impact of drought is less severe on the margins of the plains.

A COMPARISON OF THE INNOVATION OF STOCK WATER RACES AND IRRIGATION

The rate of stock water race development has been shown, at least for the Ashburton County, to reproduce the "classic" innovation curve described by Lionberger (1960). Once the stock water race idea became accepted by late nineteenth century farmers and councillors development of a large network proceeded rapidly. The development of irrigation has not proceeded as quickly or as smoothly. The reasons lie in the fundamentally different purposes of the two types of water supply.

Stock water races were essential for the continued increase of stocking rates to overcome the severe water shortages occasioned by the lack of natural watercourses on the major interfleuves of the Canterbury Plains. The stock water races were developed in conjunction with the desire for intensification of farming, for which the successful introduction of refrigeration was partly responsible. The races were also an integral part of the change in nineteenth century agriculture on the Canterbury Plains - the gradual transition from pastoralism to mixed cropping and livestock fattening. None of these movements can be said to be due solely to the construction of water races, but as Leadley (1952) comments,

> "it is generally recognised that without the system, the change could not have taken place when and to the extent it did."

Thus the relationship between stock water races and contemporary agricultural methods was complementary. Above all the introduction of a race system required no radical departure from established agricultural tradition.

This contrasts with the situation in the mid 1900s. The development and innovation of irrigation was at variance with the general trend of agriculture on the plains. An efficient system of dryland agriculture has evolved which is based on the physical and climatic resource. Farmers have been slow to respond to the advent of irrigation because several factors involved in the innovation of improved dryland farming technology tend to make it more attractive.

These factors are; a low capital input, provided familiar work routines, no new skills, and above all the practice was able to be adopted gradually.

Where irrigation has been adopted it has not always been used to its greatest advantage. This was one of the factors that lead to the conclusion in the Report of the Water Allocation Committee (1971) that ....

> "the average farmer with irrigation is in fact doing no better in this droughty climate than his dryland counterpart and indeed not so well".

This does not imply that irrigation cannot be profitable, but that irrigation farmers have not moved away from dryland practices and were using irrigation as a form of insurance rather than assurance against drought.

THE INFLUENCE OF CLIMATE

The need for an artificial system of water supply in Canterbury has been prompted by the prevailing climatic conditions. The development of nineteenth century agriculture and the role of stock water races in this development evolved complementarily with the average climatic parameter.

In the post-war period from the 1940s a system of dryland farming has evolved in conjunction with the average climatic parameter. During periods of climatic extreme the need for irrigation has been more marked and the interest and desire has also become more apparent.

Within government irrigation schemes a slight tendency has been detected for drought to precipitate investment in border-dyking. In statistical terms, perhaps 25-50% of the variance in areas border-dyked can be explained by climate.

The dates of drought periods and interest in irrigation expressed by the formation of committees for promoting irrigation has also been studied. On the basis of such scanty data meaningful analysis is difficult. Visual inspection of the dates suggests that there is an association between droughts and the expression of interest. However, periods of drought were identified where no interest was seen to occur. This suggests that other factors play a significant role.

The evidence which has been presented leads to the conclusion that climate does influence the development of water supplies. In the nineteenth century the influence was largely in terms of the average stress encountered, and the need to overcome the lack of surface water for stock. Droughts merely highlighted this need, and provided an added incentive. In the twentieth century an additional influence of climate during periods of stress has also been detected. The average climatic condition can be coped with by the advances in traditional farming methods.

It is difficult to assign a particular importance to climate, because so many other factors have been involved in the overall development. During the nineteenth century personal experiences of irrigators, political, economic and technological influences were also apparent. The twentieth century was characterised by social, political, economic and technological influences as well as climate. At any one particular point in time any one of these factors or combination of factors may have been operating.

Thus, while the climate of Canterbury may make the provision of artificial water supplies the appropriate response to overcome the problem of lack of surface water in Ashburton County in the 1860s and 1870s, for example, or the problem of land degradation in the 1920s and 1930s, the actual response has been influenced by the other factors outlined. If political and economic factors are not favourable development will not proceed, and even if the economic and political circumstances are favourable the other factors may operate against development. Therefore, it is evident that a simple cause and effect relationship is not operating between climate and the development of artificial water supplies in Canterbury.

EVALUATION

It has already been mentioned that this study has synthesized the two themes; drought in Canterbury and the development of agricultural water supplies. In terms of other drought studies it has provided a contribution to the knowledge of drought in Canterbury by the study of spatial variation. Other studies have either been general (e.g. Bondy, 1950; Johnstone, 1958) discussing the Province as a single unit, or else they have concentrated on one particular area of Canterbury (e.g. Rickard and Fitzgerald, 1960, 1969). It was hoped that the study of spatial variation would be representative of the entire Canterbury region, however, the lack of stations used from the centre of the plains, because of their short records, may make this doubtful.

In so far as the value of the soil water deficit as a measure of drought is uncertain, a checking of that arbitrary index may well be a valuable basis for future study. This study has been limited by the lack of data available on several aspects of this field which could also be usefully investigated. The confinement of this study, through lack of data, to only government irrigation schemes misses out possibly half the present development (S. Hamblett, pers. comm.).

As well this study has made no attempt to describe the continued development of stock water races after 1930. Surprisingly few County Councils have kept detailed records of such developments. The same problem was encountered during the statistical analysis of the effect of climate. Plenty of information was available on climate but there was a lack of response data, which lead to the difficulties of analysis previously discussed. Even on the schemes themselves there is no data available on the amount of private border-dyking which has occurred. Since 1970 private contracts have also been responsible for developments. This might well pose a problem in future research.

This study has only concentrated on the influence of climate upon border-dyked areas. However, if the problem of data limitations, which have hindered this study, can be overcome. The introduction of more information and the assessment of other factors may make possible the development of a more sophisticated model.

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